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ON THE ANCIENT ART OF PAINTING IN ENCAUSTIC.

BY JOHN SARTAIN.

[*Abstract of a Lecture delivered before the* FRANKLIN INSTITUTE, *April 9, 1885.*]

An opinion has prevailed, for a long time past, that the painters of antiquity never attained a high degree of skill in their art, and that the stories told by the writers, who were contemporary with the most celebrated artists of Greece, greatly exaggerated the real merit of their productions.

This disparaging judgment was based on the character of the numerous wall paintings that are to be seen in the remains of Pompeii, Herculaneum and Rome. But these pictures are only the work of mere decorators, and are wrought by a process wholly different from that practised by the great Greek artists, who did not paint on walls. They painted what were known as tablet pictures, that could be handled, and moved from place to place, like the easel pictures of the moderns. They were not in oils, nor in what the Italians term fresco, nor were they in distemper. They were in encaustic, which means burnt in.

The Greeks claim to have invented this method of painting; but there is good reason for believing that they learned it from

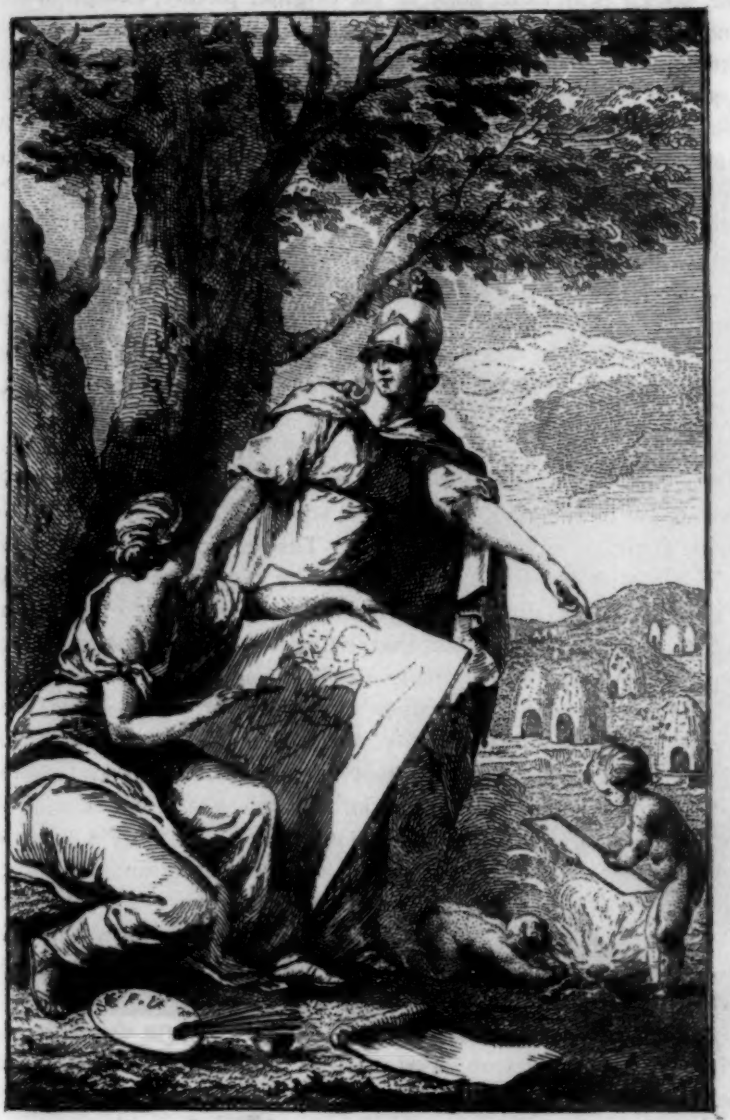
the Egyptians, who wrought in this same manner, as is proved by the remains of their work found in the tombs at Bab el-Malook, near Thebes. In Greece, the practice began before the time of Pericles, and continued into the Græco-Roman period, after which it became a lost art, when, about the middle of the last century, attention was drawn to it by the book I now show you, written by Count Caylus, who derived what knowledge he possessed from the writings of Pliny.

The examples of encaustic painting, as practised by the celebrated Greek artists, have disappeared, and those that may have survived still lie buried under the accumulated débris of ruined buildings in Greece or Italy, excepting only the two of which copies will be shown you on the screen, greatly enlarged beyond the natural size, of course.

You are all familiar with the numerous anecdotes told concerning Apelles, Zeuxis, Protogenes, Apollodorus, Timomachus, and other prominent artists, especially of those who flourished in the time of Alexander of Macedon, or about three and a-half centuries before the Christian era. One of these relates, that Apelles, in despair at his ill success in imitating the foam around a horse's mouth, flung his brush at it, and accident produced admirably just the effect he desired. This oft-repeated story is very pretty, but, like many other stories, lacks a foundation in fact. *Apelles did not paint with a brush, but with a hot iron tool, called a stylus.* It was pointed at one end for drawing outlines, and broad at the other end for laying on the paints. It had to be heated for use, because the vehicles in which the colors were ground consisted of resin and wax, in the proportions of two-thirds resin to one of wax. After the picture was finished, it was exposed to fire and burnt in. The effect produced is described as resembling enamel, but with a subdued gloss.

In the Pandects of Justinian, materials for encaustic painting are specified in the legacy of a painter, and among them the peculiar "*Cauteria*," which is the same as the "*Bas Ferrium*" of Pliny and Vitruvius, namely, charcoal braziers for heating the stylus and colors, and for burning in the picture.

As I have said, there are as yet but two ancient encaustic pictures known. The first discovered is what is designated as the "Muse of Cortona," so named from the city in which it is preserved, and near which it was found. The enlarged image thrown upon



CŒRIS PINGERE, AC PICTURAM INURERE, ETC.
—Plin. Hist. Nat. Lib. xxxv, Cap. xi.

[Frontispiece to Count Caylus' book on "Ancient Encaustic Painting," published in 1755.]

the screen is an exact copy of the original picture, except in size and the absence of color. The painting represents the figure a little smaller than life. The manner of its discovery and its subsequent vicissitudes are remarkable, and happened thus: A farmer, while ploughing in a field between Centoja and Montepulciano, turned up a large slab of slate, on which he perceived what appeared to him a picture. On cleaning it, he regarded it as a representation of the Madonna, and he placed it on a wall of his dwelling with a lighted taper in front of it. A priest, who came to administer to his sick and dying wife, told him it was a vile, heathen thing that had had a baneful effect, and that he ought to throw it out. He said if she had done harm he would do better by putting her in purgatory; accordingly, he fitted the picture to serve as the door of his oven. From this perilous ordeal it was rescued in 1735, three years after its discovery, by the Chevalier Tommaso Thommasi, the lord of the domain, and it remained in possession of the family until 1851, when Madame Louise Bartolotti Tommasi presented it to the Tuscan Academy of Cortona, which has placed it in its museum. The picture shows no sign of having suffered in the least from exposure to the fire of the oven, owing, no doubt, to the fact that, being an encaustic painting, the finishing of the work originally was by firing.

Many important discoveries of antique treasures have been made, as remarkable as this of the Cortona Muse Polyhymnia. For example, the one only copy of Tacitus that escaped the general destruction of the Roman libraries was found in a Westphalian monastery. Quintilian was picked out from a heap of rubbish that filled an old coffer. Part of Livy was found between the leaves of an old bible, and a missing page of it was found stretched on a battledore. Cicero's important treatise, "*De Republica*," was discovered concealed beneath some monastic writing. There is no time to extend this catalogue.

Mr. Holman will now show you, on the screen, a sketch of the city where the picture of the Muse is preserved, Cortona, as seen from the foot of the hill on which it stands A large portion of the original Etruscan wall still remains and nearly surrounds the city. When it was built is not known, but certainly not less than 3,000 years ago.

ON STEEL BY JOHN SARTAIN, FROM THE ORIGINAL ANTIQUE PAINTING AT CORTONA, ITALY IN THE POSSESSION OF THE MUNICIPALITY.

THE MUSE OF CORTONA.

DISCOVERED BY A FARMER WHILE PLOWING IN A FIELD NEAR CORTONA.

The next sketch is taken from alongside this Etruscan wall, looking down on the Lake Thrasymene, near which, as you will remember, the Carthagenians, under Hannibal, defeated the Romans in battle. On the extremity of the tongue of land seen protruding into the lake stands the city of Castiglione del Lago.

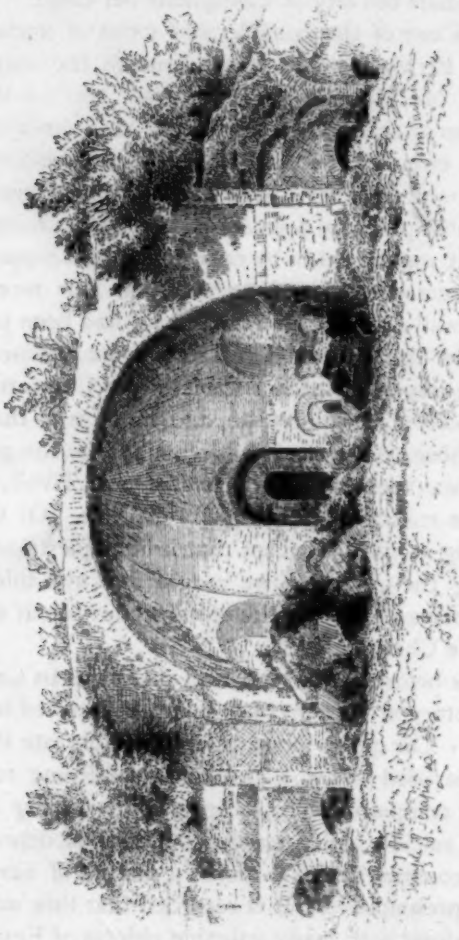
Cortona was one of the confederated cities of ancient Etruria, and, of course, Etruscan relics found beneath the earth's surface are numerous. Mr. Holman will now show you on the screen a tomb or monument that stands part of the way down the slope of the hill. It is circular, and so massive in construction, that the ruin you see, could only have been wrought intentionally, and by means of the most powerful appliances, the motive being probably superstition. It was roofed in by enormous single stones, spanning the apartment across from wall to wall, and four recesses in the interior of the wall shows where sarcophagi had been placed.

We will now leave Cortona and its pictured Muse to look on the other more important encaustic picture of Cleopatra, which is preserved at Sorrento, near Naples, and belongs to the Baron de Benneval, in whose possession it has remained for the past twenty-five years. It was found at Hadrian's villa, near Tivoli, in the year 1818, under the ruins of the Temple of Serapis. Of the Muse of Cortona nothing is known, except that it is unquestionably Greek, but concerning the Cleopatra we may arrive at a tolerably well-connected history and fix the date of its production at twenty-nine years before the Christian era.

Thirty years before Christ, the fleet of Augustus Cæsar gained the decisive victory at Actium over that of Egypt led by Anthony and Cleopatra. The queen foresaw the inevitable fate that awaited her of being paraded through the streets of Rome to adorn the triumph of the conqueror. To escape this mortifying humiliation she committed suicide, and Augustus, being thus deprived of the presence of Cleopatra herself, ordered a picture of her painted to serve as her representative. It is recorded that this was borne on a car or litter along with many valuable objects of Egyptian interest taken from the monument in which she died, and which she had collected there. After the picture had served the purpose for which it was painted, he presented it to the Temple of Saturn at Rome

Some 140 years later, the Emperor Hadrian caused to be removed from Rome a large quantity of the choicest art treasures

of the city, in order to enrich and adorn the vast villa he had built near Tivoli (the ancient Tibur) and, no doubt, the Cleopatra picture was among the objects thus removed, and it found an appropriate resting-place in the Temple of the Egyptian God



CANOPY OF THE TEMPLE OF SERAPIS, HADRIAN'S VILLA, UNDER WHICH THE CLEOPATRA WAS FOUND IN 1818.

Serapis, under the ruins of which the picture before you was found. It is well known how many of the most beautiful and celebrated statues that enrich the national museums of Europe, were dug from the ruins of this wonderful villa, as, for example, the "Venus di Medeci," the "Antinous," and other important works.

The history of the Cleopatra picture since its discovery is briefly this: Dr. Micheli, the antiquary, and his brother, who were associated in the ownership, endeavored to obtain a safe and permanent repository for their treasure in the famous Florentine Museum, through a sale to the Grand Duke of Tuscany, but the large price demanded could not be spared from the depleted treasury at a time so little removed from the political convulsions and great wars of the first French empire. Some years later the affairs of the Micheli brothers necessitated their borrowing money on the picture from some Jews, soon after which they both died. The charges went on increasing with time, and the heirs finding themselves unable to redeem it, sold it to an acquaintance of the Baron de Benneval, who liberated it from the hands of the usurers at great sacrifice. He afterwards sold it to the present owner in 1860.

The picture has given rise to voluminous literary research. Some writers claim that it is the work of the famous Byzantine artist, Timomakos, who was the author of two pictures purchased by Julius Cæsar, for a sum equivalent to $350,000. One of these was of "Medea," and the other "Ajax," the former one unfinished. He had them exposed to public view in the portico of the temple of Venus Genetrix, and afterwards presented them to the temple as votive offerings. The Greek pictures in encaustic commanded enormous prices, and cities contended with each other for their possession. The one painted by Apelles, for the City of Cos, of "Anadyomene, or Venus Rising from the Sea," was received by Augustus Cæsar 300 years later as the equivalent of $100,000, notwithstanding an irreparable injury the picture had sustained in the lower part of the figure. This work he caused to be placed in the temple of Julius Cæsar.

Some writers claim that the Baron de Benneval's picture is a *portrait* of the Egyptian queen, but it should be borne in mind that it was not painted until after her death, and then simply to represent her in the Roman triumph. It seems to be agreed that she was not so remarkable for beauty as for her accomplishments, and fascinating manners. That the end of her nose drooped below the nostrils. It is difficult to draw a comparison between the Sorrento picture, being a front face, and other accepted profile representations of her on coins, and also of the colossal one of her in the character of Isis, cut in the wall of the Pronaos to the Temple

of Dendera. I show you a portion of the latter, and also a coin in the British Museum. I did not know in time that there is a Cleopatra coin in the collection at our Philadelphia Mint, but is not easily seen because in a very obscure light.

CLEOPATRA COIN IN BRITISH MUSEUM.

The splendor of her costume in the picture before you, her jewels and the crown on her head, all correspond with the known facts attending her death. Plutarch and Dio Cassius agree in the statement that "she gave herself to death in full royal array." After she had deceived Octavius and his envoys as to her intentions, "she put on her most beautiful dress and ordered everything in the most sumptuous manner." "They found her dead, lying upon a golden couch in royal array. Of her women, one whose name was Iras, lay dying at her feet, but the other, Charmion, although she already tottered and her head swam, was engaged in setting right the diadem on the head of the queen." "There was neither swelling of the body nor any sign of poison apparent."

It is known that Cleopatra had watched experiments of the effect of adder poison on condemned criminals. "She saw that, almost alone, the bite of the adder produced a death-like sleep without convulsion or cry of pain, that the subject was to a certain degree paralyzed, having a slight perspiration on the face and a weakening of the mind, and could only be aroused with extreme difficulty, like those in a very profound slumber."

There cannot be a doubt that the death of the queen was caused by the bite of the poisonous reptile "and the Emperor himself appears to have entertained this opinion, for at his triumph a picture of Cleopatra with a firmly-biting snake was carried." Certain it is that a picture like the one here shown you was painted at that time for the above-named purpose by command of Octavius, so that she might, in a manner, be seen in his triumph along with

his other prisoners of war. The Sorrento picture corresponds with the documentary records, showing the same features that are mentioned in the accounts of Octavius' picture that was carried in the triumph on the litter with other valuable objects of Egyptian booty found in the chamber of death. All things impartially considered, the Baron is justified in pronouncing the pictures identical.

You have seen on the screen the place where the picture was found, you will now see a view of the building in which it is preserved. It is the villa of the Baron de Benneval on the Piano di Sorrento, but a short distance removed from Sorrento proper, which borders the steep cliffs that inclose one side of the beautiful bay of Naples, and here the poet Torquato Tasso first saw the light of day.

I think that the only thing remaining to be spoken of in connection with this subject of encaustic painting, as practised by the ancient Greeks, is the pigments they used, and from whence obtained. My statement must be brief, because the space of time allotted is short, and I fear to tire your patience on so dry a subject.

First as to the vehicles. From Pliny and Vitruvius, we learn that among the various tree resins, that of the Pistacia Lentiscus was used. From Rosellini, that the Egyptians used wax and naphtha. Through Pliny and Dioscoridés, that a mixture of wax and resin was used in ship painting. Geiger found that wax and resin were used in Epyptian painting, and Knixim defines the proportions as agreeing with what the Marquis Ridolfi found in the paint he analyzed from the picture of Cleopatra, namely, two-thirds resin to one-third wax.

In 1851, a quantity of painting materials was found at Pompeii, in the Street of Stabia. Beside colors, were pieces of asphaltum and resin, a mixture of asphaltum and pitch, and a great piece of bright yellow ochre that contained pieces of resin. Near St. Medard des Près were found, in the tomb of a Gallic Roman female artist, in addition to colors and paint boxes, a glass vessel with a piece of resin, which Chevreul takes to be either pine or fir, or pitch resin; also, in one phial, wax; in another, wax mixed with resin; and in a third, a black color mixed with wax and oil.

Concerning the pigments, Pliny says: "For encaustic painting, they used purple-red, indigo, Egyptian blue, white lime earth

CLEOPATRA, FROM THE CARVING ON THE PRONAOS OF THE TEMPLE AT DENDERA, EGYPT.

(calcareous earth), arsenic yellow, appianum and lead white." Migliarini says: "The white of Egyptian painting is not lead white, but a very fine and pure calcareous earth. Sir Humphry Davy says: "The white (in the colors of the baths of Titus, and in the Aldobrandini wedding) is chalk, or a fine clay. Among Egyptian colors is an especially well preserved white, supposed to be the parœtonium of Vitruvius and Pliny, so-called after the place where it was found, near the city of that name, the capital of the Lybian Nomos.

Of the yellows, Migliarini says: "The yellow (of Angelelli's Egyptian color experiments) is iron ochre" (the Latin *ocria*, or *sil*), the best quality of which, according to Pliny, was found in Attica. Davy says: "The yellow is ochre sometimes mixed with oxide of lead and chalk." Ridolfi found that the gold of the jewels of the Sorrento Cleopatra was composed of yellow ochre.

Concerning the reds, Migliarni found "a red of a very beautiful tone to be tritoxide of iron." Vitruvius places the Egyptian next to the best, which is that of Sinope. But Pliny asserts that the Egyptian and the African are the best for painters. Davy found three kinds of red, a bright red approaching orange, consisting of vermilion, or red oxide of lead, a dark red and a purple red, both composed of iron ochre, also cinnabar. Ridolfi says: "Tritoxide of iron made the red of the Cleopatra mantle, and vermilion was used in the folds."

The blue, of which Theophrastus mentions three qualities—the Egyptian, the Scythian, and the Cyprian—was invented in Egypt, and thence imported to Puteoli. According to Vitruvius, it was prepared by burning a mixture of saltpetre, sand, and chippings of copper. The eminent chemist, Sir Humphry Davy, found in this same blue (which he regards as the Egyptian) fifteen parts of the carbonate of soda, twenty parts of siliceous stone, and three parts filings of copper. But in nine ancient blue glasses of different origin, he always found cobalt instead of copper, and he is of opinion that Theophrastus confounded the cobalt with copper.

Finally, concerning the green, Davy says: "One green approaches olive green, and is common Veronese green earth. Another is like carbonate of copper, mixed with chalk. A third consists of a green copper composition with blue copper frit." Chaptel says: "The green is a mixture of green earth;" and

Ridolfi found the green of the background of the Cleopatra picture to be "a mixture of green earth and carbonate of copper."

We will conclude this brief statement of an interesting subject, by quoting the opinion of Sir Humphry Davy, that the color scale of the ancients was not inferior in scope to that of the great painters of the sixteenth century. They possessed vermilion, red arsenic, and red oxide of lead, different red earths, madder, yellow ochre from Attica, Achaia, Lydia and Gaul; Scythian and Cyprian copper blue, Lapis Lazuli, cobalt, copper green, brown ochre, charcoal and Chinese black. For colors that are not suited to fresco painting, but require a chalk ground, and can be used also in encaustic, Pliny enumerates purple, indigo, cæruleum (Egyptian blue?) white clay earth from Melos, arsenic yellow, and appianum (a mixture of blue and vegetable yellow). We will here close.

GALLO-ROMAN TOMBS.—In working a gravel pit near Minversheim, Lower Alsace, four tombs were discovered, containing glass urns filled with ashes and calcined human bones. Three of the urns were enclosed in receptacles of Vosges freestone, rudely wrought. The clay and sand in the neighborhood were completely blackened and mixed with coal and potsherds to the depth of about a metre. This indicates the presence of a furnace designed for the burning of the bodies or the purification of the soil before burial or for other funeral rites. Three of the urns contained bones of adults. The fourth, which was of much smaller dimensions and adorned with lobe-shaped ornaments, enclosed the bones of a child. Besides the glass urns there were also found pitchers and vases of common pottery, a small amphora, a plate of sigillate clay, a Roman coin, tiles of different forms, as well as numerous fragments of pottery. The custom of burning the bodies is older than that of burial in stone sarcophagi. It ceased about the middle of the second century.—*Bulletin de la Société Industrielle*, November–December, 1884.

PLAN FOR LIGHTING PARIS.—M. Sébillot devised a plan in 1881 for a tower 300 metres in height in the Gardens of the Tuileries with a lighting apparatus of 2,000,000 carcels and a reflector with a double parabolic curve. In conjunction with M. Bourdet, he has given further study to the subject in connection with the successful applications of electric lighting in New York, Denver and elsewhere, and he thinks it would be possible to provide a single electric light, which would enable all the citizens of Paris to read ordinary print. He estimates the total gas light which is now employed for public lighting in Paris at 77,000 carcels, while his luminous focus would furnish, at much less cost, 2,000,000 carcels. He suggests the possibility of utilizing the water power of the dams around Paris.—*Électricien*, February 28, 1885.

On the NEW SYSTEM of TELEGRAPHY to and from MOVING TRAINS, by the use of ELECTRIC INDUCTION.

By P. H. Van der Weyde, M. D.,
President of the New York Electrical Society.

[*Read at the stated meeting of the* Franklin Institute, *May 20, 1885.*]

Wm. T. Tatham, President in the Chair.

The President introduced Dr. P. H. Van der Weyde, who spoke as follows:

Human progress is the direct result of the discoveries how to make useful applications of substances of no value to uncivilized peoples. Coal and petroleum were stored up for countless ages in the bowels of our earth, utterly useless to the former occupants of this Continent, until scarcely a century ago the value of coal begun to be appreciated, while that of petroleum dates not much further back than a single decade.

Science and industry abound with so many illustrations of the utilization of formerly useless or waste substances, that it is scarcely necessary to enumerate more of them, while there are also many instances where such a utilization has been applied to materials which were a nuisance, not only to such a degree that ingenuity had been applied to determine the best way to dispose of them or to destroy them in the most economical manner.

It is self-evident that if it is meritorious to discover a useful application for useless materials, it is much more meritorious to discover a useful application for a substance which was not only useless but injurious—a downright nuisance.

These considerations do not only apply to material substances, but also to immaterial things, such as the mysterious agency, Electricity, of which that peculiar action, which we call induction, causes a variety of phenomena in the wires by which currents are transmitted, and which may also be called a nuisance, disturbing, as it does, the operation of telephones to such an extent that scores of suggestions have been patented, intended to destroy this nuisance, which, if now serious, while wires are suspended in the air, far

apart, will be much more so when these wires are laid close together, united in one or more cables and buried in a trench underground.

The credit of having made a useful application of this disturbing element and nuisance in telegraph wires belongs to Mr. Phelps, who recently conceived the happy idea to establish a communication of signals between a moving railway car and the stations along the railroad, by means of the mutual inductive influence of a conducting wire laid between the tracks and a similar wire suspended from a car, and parallel to the track wire, acting upon one another at a distance of several inches, which may be increased to several feet if so desired. The operation being solely based upon inductive action, requires, therefore, no contact whatsoever. Any method of contact between a moving train and the road over which it moves is necessarily very variable and uncertain, and this fact has been the cause of the failure of all former attempts to accomplish the telegraphic connection between railway stations and moving trains.

Before proceeding to explain the details of this new system of telegraphy, it may be well to give an explanation of the principle of induction, which I find is little understood, and often misunderstood. To my great surprise I have found this to be the case, even among men supposed to be competent electricians, some of whom I have heard maintain that induction was nothing but leakage of a current, which could be prevented by more perfect insulation than thus far has been applied. Now this is a grievous error; that what we call induction is no such thing as a loss of current, but a peculiar effect of the variations in a current upon neighboring conductors, which effects have been studied by Arago, Ampère, Faraday, Henry, and others. The results of these investigations have led to the knowledge of the laws, which govern this peculiar action. They are as follows:

(1.) Every electric current passing through a conducting wire, which we will call the primary wire, possesses the power to cause other electric currents to be generated or induced in neighboring wires, placed parallel or nearly parallel to the primary wire. These neighboring wires we call secondary wires, and the currents generated in them, secondary or induced currents.

(2.) Those secondary, or induced currents are not developed as long as the primary current generated by a galvanic battery,

dynamo, or any other source whatsoever, is steady; that is, invariable, or without fluctuation or interruption. Under these circumstances, a wire conducting a current exerts no more influence upon neighboring conductors than if there were no current at all in the primary wire.

(3.) As soon, however, as any change in the primary current takes place, currents are developed in neighboring wires, which are found to flow in the direction of the primary current at every break or decrease of the latter, and to flow in the opposite direction of that of the primary at every make or increase of the latter.

(4.) The strength and character of these induced currents depend upon several factors. 1. The electro-motive force of the primary current as measured in volts. 2. The quantity as measured in ampères.

Before proceeding further, it may be well to add here a few words in explanation of these terms, for the benefit of those present who are not familiar with what, at the present day, is known about electrical matters. While it is sure that electricity is not a fluid flowing through metallic wires, like water through pipes, it behaves in many respects, in a similar manner. Water drawn from pipes may flow in greater or smaller quantity, or it may escape under greater or less pressure, or head—two very different conditions. It is the same with electricity, which may flow through a wire in greater or smaller quantity, depending upon the size of the plates in the generating battery, or the thickness of the wires of the dynamo. The current may also flow with greater or smaller electro-motive force, which depends upon the number of battery cells connected, or the length of the wires of the dynamo. This explains to you what is meant when, in stating the qualities of a dynamo, the two terms ampères and volts are used. The first refers to the quantity of electricity produced, the second to the intensity, pressure or head under which it escapes. I ought to add here that in order to make a current dangerous, there must be enough of each. A current of great intensity, like that of a small friction machine, may have electro-motive force enough to jump over a space of one or more inches, and give a shock to the body, still it may be harmless if its quantity is so insufficient that it can hardly be measured; while on the other hand, the current of a very large voltaic cell may be powerful enough to burn up a piece of iron

wire, but will also be harmless, because it has not enough intensity to be able to pass through the human body. It is only when currents combine both conditions that they become dangerous, as is the case with large arc-light dynamos and with lightning.

The third factor upon which the strength of an induced current depends is the manner of fluctuation and interruption of the primary current, which may be more or less gradual or sudden, and causes the induced currents to display accordingly more or less electro-motive force, and less or more quantity.

The fourth factor is the mutual inclination under which the wires are placed, whether they are more or less perfectly parallel, while the amount of induction produced is proportional to the cosine of the angle which the wires make together. This cosine is at its maximum when the angle is zero, which is the case when the parallelism is perfect, and it is zero when at right angles, in which case there is no induction. This, by the way, has given rise to several patented devices, such as solenoid cables, interlaced conductors, etc., in all of which the inventors attempted to overcome inductive disturbances by crossing the conducting wires as much as possible at right angles. It is, however, evident *à priori*, and confirmed by experience, that such devices are not better than the straight, double metallic conductors as used by Morse with his first telegraph from Washington to Baltimore, before it was known that the earth could be used for the return currents, while the greater length of wire required increases unnecessarily the resistance, and reduces the distance accordingly, which would otherwise be reached by a given battery.

A fifth factor which influences the strength of inductive influence received by a secondary wire, is the distance under which it is placed from the primary wire; when close to it, the influence is at its maximum, while it decreases with the increase of distance, and this in the inverse ratio of the distance.

A sixth factor is the material which separates the wires; when this is a non-conductor, it is of comparatively little influence, except that the very best non-conductors interfere the least when inductive action is desired to be transmitted.

The seventh factor is the presence of other conducting *media* in the neighborhood. This is a very important matter, even when these *media* are not between the wires, but only within the sphere

of the inductive influence of the primary current. In this case, its inductive capacity may be so much spent or wasted by the induction of currents in these neighboring conducting *media*, that little inductive action is left for the secondary wire, in which we may wish to develop induced currents. This is the principle upon which many devices are based, serving to regulate the strength of induced currents, with which, however, we have no time to occupy ourselves at present.

I will now call your attention to the practical illustrations of the principal laws of induction which I have summarized. In order to make the motion of the galvanometer, by which the existence of currents is detected, visible to the whole audience, the little instrument is placed in the magic lantern which stands here among you, and the magnified image is projected on the screen behind the platform. You see that the galvanometer is connected with a flat coil of copper wire, which is laid on a glass plate resting on an insulating support at a distance above the table, and has no other connections whatsoever. On the table, under the support, rests another similar coil, connected with a galvanic battery by the intervention of a telegraph key. When I now depress the key, and thus close the current, you will see a movement of the galvanometer needle, but, as it returns at once to its original position, it shows that the current lasts only an instant, notwithstanding I keep the circuit closed, and thus make the battery current continuous. At the instant, however, that I lift my finger from the key, and thus break the current, you see the needle move again, but in the opposite direction, as before, proving that the secondary or induced current runs now in the opposite direction from the current developed at the instant of closing the primary circuit. This proves that the secondary currents are only developed by the making and breaking of the primaries, and, in fact, also by any fluctuations in their strength, as before mentioned.

As there is no conductive connection whatsoever between the battery and the galvanometer, to which I wish to draw again your special attention, it is evident that the latter instrument is acted upon by some other force than the direct battery current, namely, its inductive influence, which cannot be prevented by any intervening insulating material, but only modified and weakened by other

conducting bodies, placed within the sphere of the inductive influence. This latter fact, by the way, is the basis upon which the induction balance is based, by which the presence and positions of hidden metallic bodies may be detected, and which occasionally has been applied in surgical investigations.

The telephone being a more delicate apparatus than the galvanometer, we can by its means detect much weaker currents; in fact, such as are developed when we place the coils at several feet distance. I will now illustrate this by attaching, in place of the galvanometer, a telephone to the coil, and any one who wishes to listen can now become satisfied that inductive influence will act, not only at the distance of several inches but of several feet. I lift secondary coil several feet from the table on which the primary coil rests; in fact, I can lay the latter on the floor under the table, and still you will hear the click of the telegraph key in the telephone, showing how the ordinary Morse signals can be transmitted at a distance through the air, without any direct metallic connection.

This now is the basis upon which Phelps' telegraph system for moving trains is operated. The details of which will, by the kind coöperation of some of the officers of the FRANKLIN INSTITUTE, be projected before you upon the screen.

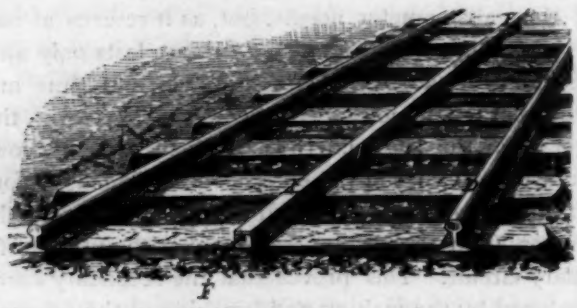


FIG. 1.

Fig. 1. represents a part of the road; between the rails is seen the wooden protection containing the main line, which is an insulated conducting wire, of which the two ends are connected at both stations, each of these containing a signaling and receiving apparatus, battery and ground connection.

Fig. 2 represents a car, in one end of which, in a corner, is a closet containing also a signaling and receiving instrument, separ-

ately represented in *Fig. 3*. Inside the closet is the battery used for signaling from the train, and a single cell connected with a polarized relay, by which messages are received, and which is

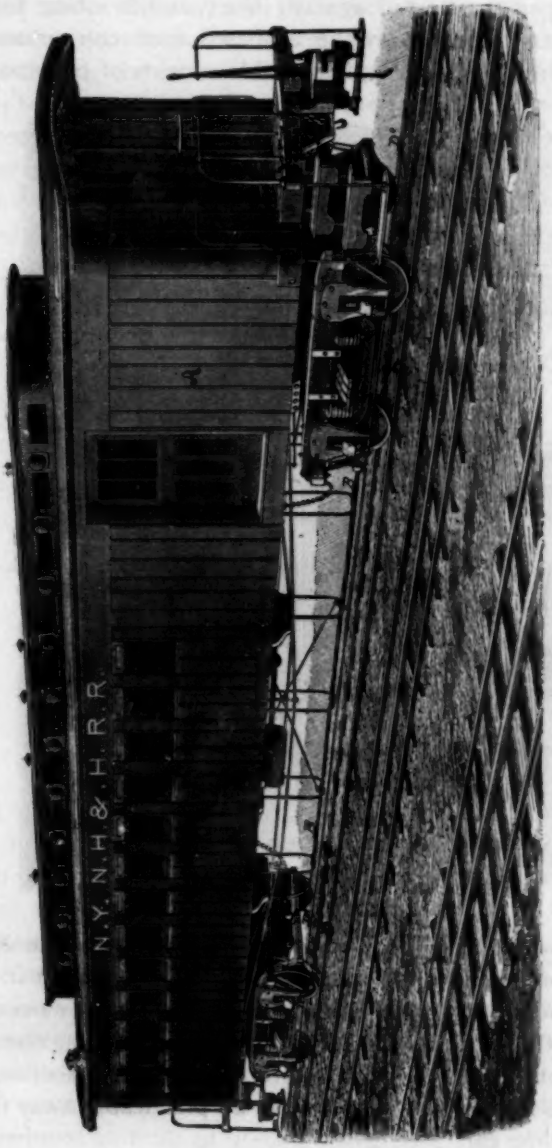


FIG. 2.

placed under a glass shade on the top of the closet, as seen in *Fig. 3*, and of which *Fig. 4* shows the details.

Under the middle of the car, *Fig. 2* is suspended an endless cable, properly protected against injury, and reaching to within eight or ten inches above the insulated conductor or main line between the rails, *Fig. 1*. This cable consists of one continuous

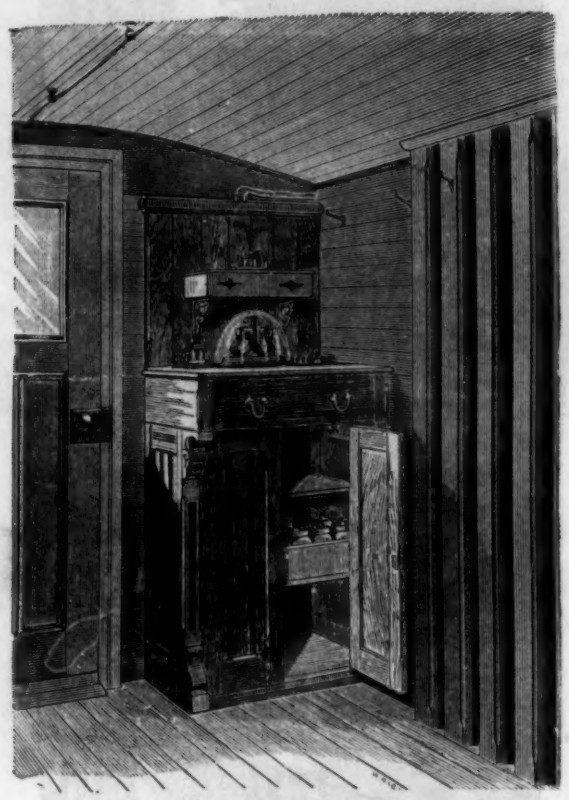


FIG. 3.

insulated wire, wound up like a coil, of some forty feet in diameter, of which one-half is under the car, and the other half near the top of the same, so that in the portion under the car the currents must all run in the same direction. In place of neutralizing one another by the contrary directions, therefore, the effect of induction is multiplied, the return half being as far as practicable away from the half under the car.

It is clear that if now a current is sent through the main line, *Fig. 1*, it must exert an inductive influence upon each and every wire in that portion of the cable nearest to it; that is, the portions suspended under the car, and the effect will be strengthened, in fact, to such a degree that when the two ends of the continuous wire constituting the endless cable are connected with the polarized relay, its tongue will be thrown from the right to the left, and *vice versa*, every time the current sent from either station through the main line is closed or interrupted, or what is more effective, every time the current is inverted. This polarized relay closes and opens the circuit of a single cell of the local battery, placed in the closet

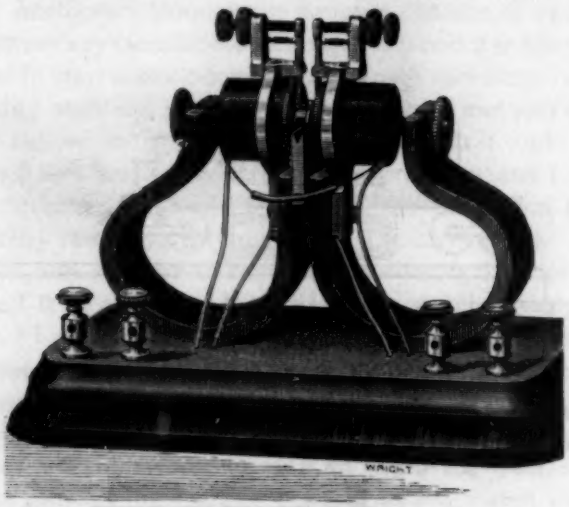


FIG. 4.

(*Fig. 3*), which cell works a sounder; or, what experience has proved to be more audible above the noise of a railway train, it is made to work an automatic contact-breaking buzzer, in which the dots and dashes of the Morse alphabet are given with more distinctness than is the case with the Morse sounder.

In order to signal from the moving train, a battery of four to six cells is used, of which the current is sent through the windings of the endless cable, the two ends of which windings are then connected with battery and key, or better, a reversing key. The battery current in the cable, multiplied by its windings, will now evolve induced currents in that portion of the main line under the

car, and this with sufficient energy to be made perceptible at the stations, in the same way that the currents evolved in the cable are received in the car, namely, with a polarized relay, local battery and sounder of any kind.

I have before mentioned the great sensitiveness of the telephone for weak currents, and its use has been found very advantageous, enabling the operator to receive signals even when the train runs on the track adjoining the one provided with the main line. In this case, the induction acts over a distance of eleven or twelve feet.

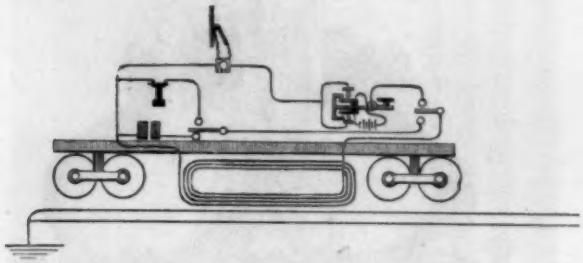


FIG. 5.

Our next projection (*Fig. 5*) gives, perhaps, a clearer idea of the operation. At the left side, is the receiving telephone and switches, at the right side, the battery and transmitting instru-

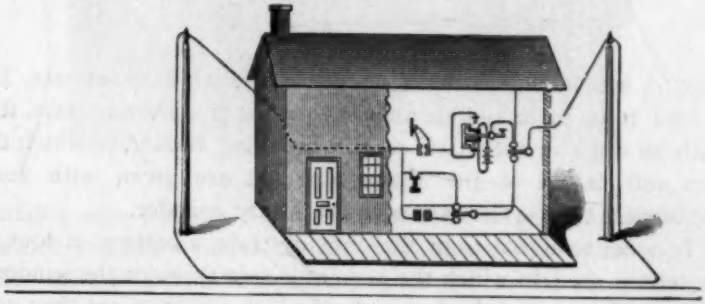


FIG 6.

ment; while here (*Fig. 6*), we have the interior of a station containing the same details, and receiving the signals by the action of

the main line upon a wire placed parallel to the same, and acted upon by induction after the same principle that the cars receive the messages.

I wish to call especial attention to the fact that the figures represented on the screen are no fancy sketches, but correct representations of the experimental car which is running daily from Harlem Bridge to New Rochelle, N. Y., and is attached to a local train between those two places.

The ELECTRICAL SOCIETY in New York was invited to visit an exhibit of this invention. Among the members were several practical telegraphers, who could not imagine the possibility of conveying intelligence through the air at a distance of one or more feet without any metallic connection. They said it is the old story: in order to start a stock company, it is only necessary to advertise something startling, in the Keely motor style, and make ignorant people believe in it. But I was satisfied that it could be done, because I had studied induction for many years, and I wanted to convert others. We had a meeting of the Society on board the car. They came in great numbers. The car was full. I wrote a despatch, and in order to convince unbelievers I wrote a copy of it, sealed it up and gave it to one of the members to put in his pocket. I sent a man along the track to catch the despatch some distance above the station. I was at the side door of the car when we passed the place, and saw the man pick up my despatch and go back to the station. As soon as he could have entered there the telegraph commenced to work on board the train, and in two or three minutes the operator handed me a despatch identical to the one I had sent. This was a satisfactory test, and did away with all possibility of any idea of collusion.

I made another experiment. While returning, I sent a message from the car to the next station, and the moment we arrived a messenger was on the platform and handed me a despatch which was identical with what I had sent. So, practically, there was no doubt about it. Any one who has studied induction can be satisfied with the possibility of the operation.

It is evident that in this way an always ready communication is established between any two stations, and the trains in the section between them, so that a train, no matter if in motion or at rest, can receive a signal sent from either station, and inversely can signal to

them. Of this I saw an illustration last week, when the brake connection gave out, it was at once telegraphed to the next station, and when arriving there a few men were already waiting on the platform with a new connection, and put it on without delaying the train. It is also found very useful to regulate with great despatch the movements of the hands employed, who, often, are suddenly needed at a particular place, even in the regular business, especially in regard to freight.

But the all-surpassing advantages of this system is that every station master knows always where the trains are in the section or sections under his control, and can stop or start them at any time, while the train conductor can at once report any accident to the stations, so that there is no doubt that several deplorable collisions and loss of life, still fresh in our memories, would have been prevented if this system had been invented and introduced some years ago

The expense is comparatively a trifle, amounting to not more than the laying of a single insulated wire, properly protected, along the track; while the apparatus will cost scarcely $100 for both car and station. The wire costs only about double that of ordinary telegraph wire on poles above ground.

DISCUSSION.

THE SECRETARY.—"Mr. President, I think it is best to defer further practical illustrations till the close of the meeting, when the members can listen at the telephone, hear the signals, etc."

THE PRESIDENT.—"Any question on this interesting subject?"

THE SECRETARY.—"Mr. President, it seems to me, unless I very much over-estimate the value of this invention, if it is practically operative, as Dr. Van der Weyde has given us to understand—and I have not the least doubt that it is, from the accounts I have read of it, and his lucid explanations—it seems to me that it opens an entirely new field in the application of electricity to railways, and that it is an invention of the highest importance. As all present are aware, the railway companies of this and other countries have expended large sums of money in the establishment of very expensive plans for signaling, *despatching trains*, etc., for the purpose of effecting safety. It must occur to any mechanical mind that a practical system whereby telegraphic or telephonic despatches may be received on a moving train, and sent from a moving train, must

be infinitely more safe than the most perfect automatic signaling system that could be devised. From this point of view, I am satisfied that the Phelps system, if not itself a solution of the problem, is a great step towards it, and certainly a very important invention."

A MEMBER.—"I notice in his drawing that it appeared at the station as though a secondary wire were connected with the key. I would ask if it is the primary wire connected with the battery at the station, or is it a secondary wire similar to the one on the train?"

DR. VAN DER WEYDE.—"At the end stations no secondary wires are used. They switch the battery off and switch on the telephone. *Fig. 6* represents a way-station, not connected with the main line, but receiving the signals from the main line, by induction through a secondary wire, laid along the track, on the same principle that the cars receive the signals."

[After answering a few more questions, a further opportunity was given to many of the audience to hear the signals in a number of telephones, connected with the secondary wire, placed from the primary at distances varying from six inches to six feet, where they were still audible, even when several persons placed themselves between the primary and secondary coils. This was similar to an experience of last winter, when snow and slush, entirely covering the main line between the track, did not in the least interfere with the transmission of the signals.]

DELTA METAL.—More than twenty years ago, Aich and Baron Rosthorn obtained good results by introducing a little iron into alloys of copper and zinc. A London coppersmith, who made such alloys, informed Alexander Dick, of Düsseldorf, that he sometimes obtained an excellent metal, but that the results were so irregular, that he was obliged to give up its use. M. Dick studied the causes of the irregularity and found that they could be mostly overcome by dissolving iron to saturation in melted zinc and adding the alloy, with or without additional zinc, to melted copper. A small proportion of phosphorus prevented injurious oxidation during the process. An extensive and complete series of experiments led to the discovery of a number of definite and valuable products, each of which has special useful properties, all being included under the common name of delta metal, *delta* being the Greek name of the initial letter of the inventor's surname.—*Société des Ingénieurs Civ.*, October, 1884.

A LECTURE ON "MATTER," INCLUDING "RADIANT MATTER."

BY ALEXANDER E. OUTERBRIDGE, JR.

[*Delivered at the International Electrical Exhibition of the* FRANKLIN INSTITUTE, *October 9, 1884.*]

The Chairman of the Committee on Exhibitions introduced the lecturer, stating that, by request of the Committee, Mr. Outerbridge would repeat an address, which he delivered before the INSTITUTE in 1881, adding thereto the results of some of the more recent investigations on the nature of matter. The lecturer, after a few introductory words, spoke as follows:

The ideas which have prevailed in the past, in regard to the nature of the ultimate particles of matter out of which worlds are formed, reveal the speculative tendency, as well as the intellectual status, of the human mind in different epochs of the history of civilization. The present era might very well be designated as an interrogatory age, for is there not an evident tendency to question Nature eagerly, to accept nothing on the evidence of tradition, and but little comparatively on the basis of pure hypothesis?

Plausible explanations of various phenomena have so often been accepted with confidence, only to be overthrown by others equally unstable, that the mind has become, as it were, suspicious, and demands the most rigid physical tests to corroborate new theories. The experimental feature of scientific study has thus been stimulated until it has attained an importance and perfection never before approached, and this cause largely contributes to popularize even the most abstruse subjects of inquiry. It is one of the little pathways through the intricate mazes of Nature's mysterious realms that we propose to explore together this evening.

The question, "*What is matter?*" is one that has exercised the intellects of the profoundest thinkers in all ages, and it is, apparently, as far from being definitely answered in this nineteenth century as in the classic days of the Greek philosophers. It would seem, indeed, that the modern views of matter, based upon strictly scientific data and mathematical reasoning, approach in some respects quite closely to those propounded by the Attic

philosophers, which were evolved purely from the inner consciousness of these poetic sages and must be regarded rather as expressions of sentiment than as deductions from observed facts. The poetical fancies of Lucretius, which have been preserved to us in his great work, "*De Rerum Natura*," through a lapse of 2,000 years, may be read with renewed interest in the light of modern scientific thought.

The delicacy of the apparatus devised by modern physicists, and the refinement of experimental research rendered possible thereby, are among the greatest marvels of this wonderful age. The physicist is pushing his researches into paths which but a few years ago were thought to be forever hidden somewhere in the vast realm of the "unknowable," and the boundary line between so-called physical and metaphysical science is continually narrowing; the philosopher has advanced, step by step, until he seems almost to have grasped the ultimate particles which constitute the physical basis of the universe, and to have revealed to mortal eyes particles of matter which are too minute even for the mind's eye to conceive.

Our ideas of size and weight are purely relative, and that which appears a small or light object from one point of view, may become large and heavy by a different comparison. To most of us, perhaps, a "grain weight" suggests a little thing; we know that the apothecary and a few other exact dealers split up the grain into halves, quarters, tenths, and perhaps even hundredths, but we are apt to regard such discriminations as bordering on the fanciful; yet, strange to say, there seems to be a sort of vanishing point in our minds, beyond which, if an object is small enough to pass, it becomes larger and more important in our estimation by reason of our astonishment at its minuteness. The most ordinary microscopical specimen is an illustration of this, but when we realize that the ability of the spectroscope to reveal small particles of matter begins where the finest microscope searches with its highest power in vain, that the grain of matter may be divided, not merely into hundredths, or thousandths, or tens of thousandths, but into millionths and tens of millionths, and that a single one of these particles may be readily detected by this little searcher and held up for our inspection, our wonder and amazement enhance our respect for its occult powers.

The astronomer tells us that a comet often throws out a tail longer than the distance between the earth and the sun, and broad

in proportion; yet the matter forming this tail is so attenuated that, if it could all be gathered up and properly compressed, it might be carted away in a wheelbarrow, yet we have merely to point this little tell-tale at the comet and instantly we perceive what the matter is! Think of it! Not merely may we grasp infinitesimal particles at our hand, but we may sweep the firmament, "gather up the star dust" and tell its composition. But we have not yet reached the end of our scientific excursion; indeed, we have only entered the threshold of the scientist's sanctum, and the wonders of the arcanum eclipse those of the portico.

That mysterious agency, or force, called electricity, has been utilized not only for hundreds of practical purposes, so fully illustrated in this grand exhibition, but it has been employed by the physicist as a sort of fairy finger to probe Nature's inmost structure, and it has enabled him not only, as it were, to see her mind but, in some sense, to feel her pulse.

Professor Crookes, in his beautiful investigations on "radiant matter," has availed himself of this index, with the most surprising results. Here are a number of his tubes and bulbs, from which he has exhausted the air until only about $\frac{1}{1,000,000}$th part of the original quantity remains. We may regard this residual matter as consisting of many millions of individual molecules, and we can capture these minute particles and compel them to do tangible work. This tube, for example, contains a sort of miniature railway, which is to be operated by projecting these particles with great force against the driving wheel of the engine. Here is a little wind-mill which is to be similarly driven. Here is a tube containing a piece of refractory metal, platinum, which is to be so terribly battered by hitting it with a rapid succession of charges of these molecular bullets, that it is made to glow with a bright light, and if the bombardment should be continued to melt before it like wax. Here is a tube containing a common piece of chalk which may be made to shine with a luminosity rivalling the famous "Koh-i-noor." Even little pieces of glass may outshine the finest emeralds, rubies, and sapphires, when under the marvellous influence of this philosopher's wand.

You must not imagine that these little tubes are merely scientific toys, they are designed to illustrate new properties of matter; but before exhibiting their beautiful effects, I wish to familiarize you

with some of the modern ideas in regard to the nature of the ultimate particles of matter. I am sensible of the difficulty of attempting to elucidate to a general audience, in a brief period of time, a subject so abstruse in character, so bound up in mathematical deductions and dealing with such minute figures as this. I shall try, therefore, to lead you by gradual and easy steps up to that point of observation from which the philosopher reviews, by the aid of his acute mental vision, the transcendent processes eternally operating in Nature's workshop, whereby the most complex structures are evolved from simple elements.

The idea that motion is intimately associated with all matter in some way is not a modern notion, and it was regarded by Faraday's far-reaching mind as a sort of necessary concomitant of familiar matter, though the time was not yet ripe for its full development as a scientific theory. The great forces, light, heat and electricity, were formerly thought to be ponderable substances, which might be squeezed out of a body like water from a sponge; now they have all been resolved into mere "modes of motion," and it is not illogical to infer, from the general drift of modern scientific speculation, that the now seemingly complex laws of Nature's operations may all come, eventually, to be included in the study of the laws of motion.

Sir William Thomson said, in his address at the meeting of the British Association in Montreal: "It is scarcely possible to help anticipating, in idea, the arrival at *a complete theory of matter in which all its properties will be seen to be merely attributes of motion.*"

Before endeavoring to explain such a strange proposition (for it must, no doubt, at first, impress an intellectual person who is not familiar with the course of reasoning upon which it is predicated, as incomprehensible), it will be well to consider briefly some of the properties of matter with which we are more familiar, such as its wonderful divisibility, its universal porosity, and its universal transparency. The metal gold, for example, is susceptible of visible dissection to a remarkable degree. The gold beater, as you doubtless know, will hammer out the metal into leaves so thin that more than 4,000 are required to make a pile one millimetre in thickness. But vastly thinner gold leaves may be obtained in another way. By electro-plating a known weight of

gold upon one side of a sheet of copper foil of given dimensions, a coating of gold may be obtained upon the copper whose thickness is readily ascertainable by a simple calculation; then, by using a suitable solvent, the copper may be removed, when the leaf of gold will remain intact.

After a series of careful experiments, I have obtained, in this way, sheets of gold, mounted on glass plates, which are not more than $\frac{1}{40,000}$th of a millimetre thick; and I have some specimens to show you which I have good reason to believe are not more than $\frac{1}{400,000}$th of a millimetre. To give you an idea of this thickness, or, rather, thinness, I may say that it is about $\frac{1}{200}$th part of a single wave-length of light. Such figures are not hap-hazard guesses, but are based upon reliable and understandable data, and are easily susceptible of verification.

We cannot claim for the thinnest of these films that they represent a single layer of molecules. Taking Sir William Thomson's estimate of the size of the final molecules, and considering that each layer corresponds to one page of a book, our thinnest film would then make a pamphlet having more than a hundred pages. It is found that when such a film is interposed between the eye and any object, it is as transparent as a piece of glass. This may be readily proved by projecting a picture on the screen and interposing the leaf of gold in the path of the light and you see that the only apparent effect is to tinge the light a pale greenish color, none of the detail of the picture is lost, though all the light is coming through a piece of gold as absolutely continuous in its structure, when examined under a microscope, as though it were an inch thick. By placing in the lantern a piece of ordinary gold leaf, having a thickness of about $\frac{1}{200,000}$th of an inch, and a piece of electro-plated gold leaf about $\frac{1}{3,000,000}$th of an inch thick, mounted side by side on a glass slide and focusing their images on the screen, you will see a very great difference in the amount of light transmitted by the two, owing to the difference of thickness. Plates of platinum and other metals similarly prepared are equally transparent; indeed, all metals, and probably all substances are transparent when reduced to sufficiently thin plates.

Faraday made some most interesting investigations on the size of finely-divided particles of gold diffused through various liquids and he obtained gold films by reducing gold from solution by phosphorus

which he thought were not over $\frac{1}{100}$th part of a single wave length of light, but he had no means of determining their thickness accurately as we have in the case of these electro-gold films, where, knowing the weight of gold deposited and the surface covered, the exact thickness may be directly calculated. By treating these thin films after they are attached to the glass plate with a weak solution of potassium cyanide they may be still further reduced in thickness until the film becomes so transparent as to be incapable of reflecting the usual gold color.

Tyndall tells us that the blue color of the sky is due to reflection of light from innumerable particles or spherules of floating matter. He has reproduced the sky phenomena by artificial means, and he tells us that the matter forming the real sky is so attenuated that if it could be properly gathered up and compressed, a gentleman's portmanteau would probably hold it all; and he says, further, "Whether the actual sky be capable of this amount of condensation or not, I entertain no doubt that a sky quite as vast as ours, and as good in appearance, can be formed from a quantity of matter which might be held in the hollow of the hand."

We might naturally suppose from these considerations that no absolute knowledge could ever be obtained regarding the nature of the infinitesimal particles out of which worlds are formed. It was thought in former days that the human mind could never hope to take cognizance of such minute portions of matter as constitute the ultimate molecule. One very eminent scientist said, "Data cannot be furnished by observation or experiment on which to found an investigation of it." Yet so great has been the progress of thought in recent years, aided by the wonderfully delicate means of research at command of the modern physicist, that Sir Wm. Thomson now claims that the ultimate molecules are "pieces of matter measurable dimensions, with shape, motion, and laws of action: of intelligible subjects of scientific investigation." The same eminent author has deduced, by four different and equally profound methods of calculation, the probable size of these molecules, and in order to make his dimensions intelligible to ordinary people, he asks us to imagine a single drop of water magnified to the size of the earth, the molecules of which it is composed being increased in the same proportion, "the structure of the mass would then be coarser than that of a heap of fine shot, but not so coarse as that of a heap

of cricket balls." You know that the gases oxygen and hydrogen when united to form water are greatly compressed, yet the atoms are far from being in actual contact; the estimate has been made that the particles composing a drop of water are not nearer together when compared with the spaces between them, "than 150 men would be if scattered over the whole of England, or one man to 400 square miles." To the ordinary mind this seems incredible.

In order to comprehend the modern idea of the nature of matter, you should try to realize that the molecules composing even the most dense solid substances with which we are familiar (such as gold, platinum, etc.,) are not in contact, and are free to move within certain well-defined limits. In the fluid condition of matter, these particles have a wider range of motion; while in the gaseous state, the excursions of the molecules are limited only by the size of the containing vessel.

All the phenomena of gases are now explained upon the assumption that the molecules are constantly flying about and hitting against each other, and the characteristic properties of gases are directly traced to this state of constant collision among the molecules; in scientific phraseology, this dictum is called "the kinetic theory of gases."

Professor Crookes has gone still farther upon this road; by exhausting the air from his tubes to a very high degree of rarefaction, he has so greatly decreased the number of molecules and correspondingly increased their house room, that collisions occur among them as they fly about with far less frequency than before, hence the ordinary characteristics of gases disappear, while a whole new series of phenomena are developed. It is upon the visible evidence afforded by the peculiar behavior of the so-called "radiant matter" in these tubes, when under electrical excitation, that Professor Crookes rests his claim to have revealed matter in a state "as far removed from gas as gas is from liquid, or liquid from solid," and he calls this new condition the "fourth state of matter." Whether this claim rests upon a sure foundation and is destined to be recognized as true, I do not venture to form a decided opinion, but that he has revealed new phenomena of a surprising and beautiful nature, we have incontestable evidence before us in these remarkable radiant matter tubes.

Now, let us try to approach a little nearer to an understanding of the idea recently elaborated by Sir Wm. Thomson, in his Mon-

treal address (entitled, "Steps toward a Kinetic Theory of Matter,") that all the properties of matter with which we are familiar are merely attributes of motion. Those of you who heard his lecture in this city, on the "Wave Theory of Light," will remember that he said that the luminiferous ether is no longer to be regarded as hypothetical, but that it is one thing which we are sure of; furthermore, that it may be regarded as a substance having great rigidity, and therefore capable of acquiring motion at the rate of millions and millions of vibrations per second—in the case of visible light waves giving from 400,000,000,000,000 to 800,000,000,000,000 per second.

Now with regard to the character of the atom. Suppose that a particle of this all-pervading, highly-attenuated, rigid yet elastic substance, which, for want of a more appropriate name, is called "the luminiferous ether," be endowed, by a creative act, with rotary motion; it is evident, to a thinking mind, that new properties would be imparted to the particle by virtue of this motion, just as new powers are imparted to grains of sand when caught up and carried along in a whirlwind, or to particles of water forming a water-spout. Suppose that no opposing forces, like gravitation, tend to annul this motion, then the particle will remain forever differentiated from the great mass of ether in which it has its being. This is the simplest explanation, as I understand it, of Sir Wm. Thomson's "vortex-atom," he believes that "what we call matter," may be only the rotating portions of something which fills the whole of space.

Helmholtz's investigations on the nature of rotary motion, in a theoretically perfect fluid, prepared the way for the vortex-atom, and the now well developed "kinetic theory of gases" is the natural precursor of the "kinetic theory of matter," which, although still in the embryonic stage, gives promise of developing into more than a mere scientific speculation, and of emerging into an accepted theorem. The creation of a new theory is generally, and very properly, a slow process; for when once established it clings tenaciously to the mind, and if fallacious, it sometimes fetters the progress of human thought for many generations.

Following in this mental path, Professor P. G. Tait says: "This property of rotation may be the basis of all that appeals to our senses as matter." Professor Crookes likewise says: "The space

covered by the motion of molecules has no more right to be called matter than the air, traversed by a rifle bullet, to be called lead." Again he says: "From this point of view then matter is but a mode of motion."

In order to render the distinctive characteristics of Professor Crookes' radiant matter phenomena apparent to those not already familiar with the subject, we will first exhibit a number of very beautiful Geissler tubes, *i. e.*, tubes from which the air has been only partially removed. These tubes are of great size, and are marvels of the glass-blower's art. You will observe that the tubes are of various and complicated form, and contain spirals, bulbs, and goblets of different kinds of glass. A platinum wire is hermetically sealed into each end of the tubes. Here is a large coil of wire, called an "induction coil," having a smaller central coil which you do not see. A galvanic battery on the stage supplies an electric current which passes through the centre coil; an automatic break piece makes and breaks connection rapidly between this coil and the battery; the terminal wires from the large exterior coil are connected with the platinum wires entering the Geissler tube; when the electric lights illuminating the room are extinguished and the battery is put in operation, a succession of induced electric pulsations of high tension will be sent from this exterior coil into the tube. Now, you see it filled with brilliant and beautiful light. Observe that the electric flashes seem to pervade the whole tube, and to follow all its intricate twists and turns. Here is another tube exhibiting the curious phenomenon of "stratification" in a remarkable way. Here is another, which is divided into separate compartments containing traces of different gases, and you see that the color of the light is different for each gas.

Passing on, now, to the Crookes tubes, we will show them in the order adopted by Professor Crookes, on the occasion of his original address before the British Association, projecting on the screen, at the same time, diagrams showing their mechanism, omitting some tubes which have become injured on the journey across the water, and including others of recent device.

The tube having a negative terminal in the centre and a positive one at each end, showing the "dark space" surrounding the negative pole and exhibiting "the mean free path" of the molecules, is most interesting.

Another tube with one negative and three positive terminals showing that radiant matter always travels in straight lines independently of the position of the positive pole, and still another showing that radiant matter will not turn a corner, prove conclusively that the phenomena differ widely from those exhibited in the Geissler tubes, where the electric current followed all the convolutions of the tube, entering at one terminal and emerging at the other.

[The tubes showing mechanical action were exhibited by projecting the images of the moving vanes, etc., upon a screen by means of a lantern.*]

The lecturer said, in conclusion: Although I am conscious of having imperfectly succeeded in my effort to elucidate so large a subject as the modern conception of the nature of matter, in the brief time allowed, I still venture to hope that this little glimpse I have given you into the minute world of molecules and atoms (which has been compared to the great world in which the stars revolve), may tempt you to explore more deeply the interesting paths of knowledge here indicated, which have been opened to view by toiling investigators who have taken the light of "pure science" for their guide and have done much to enlarge the horizon of our mental vision and to expand our intellectual capacities.

It is interesting to note how frequently it happens that original investigators, working from different standpoints and with dissimilar objects in view, will, independently of each other, accumulate a mass of observations all tending to elucidate some hitherto unexplained physical law, which only require to be collated in order to reveal their true significance.

Such an original investigator in Nature's domains may be compared to a pioneer who penetrates a primeval forest, hewing down, with his keen hatchet, first a narrow pathway through the wilderness which he explores, until he reaches a favorable camping ground; he then clears a space admitting sun-light and air and

* A detailed description of Professor Crookes' "Radiant Matter" will be found in the JOURNAL OF THE FRANKLIN INSTITUTE, vol. cviii., No 5, p. 305, and a reprint of Professor Crookes' papers on the subject with illustrations, has been prepared by Messrs. J. W. Queen & Co., of this city, from whose exhibit the apparatus used in this lecture was obtained. For these reasons the details of these beautiful experiments are omitted in this report.

erects his habitation; meanwhile, perhaps, other adventurers approach through the forest from different directions; presently the clearings begin to encroach upon each other, cultivated fields appear, the rugged face of the landscape gradually changes, its every aspect becomes familiar, and its once strange and novel features cease to excite wonder or remark. This analogy is not a mere fancy, all the advances in scientific knowledge have been made in little detachments. Narrow lines of investigation have been projected and explored by patient toilers who dig out a few roots here and there, which are carefully garnered until their genus can be determined by further study. In this way separate facts are being constantly stored up, to be collated and classified at a proper time.

While we, matter-of-fact people, may not understand the motive that induces the original investigator to plod on in his narrow path, continually prying into some obscure corner of Nature's vast forest of mysteries, we can all appreciate and enjoy the beautiful results which modern science offers as rewards to her votaries, and we cannot too greatly venerate the genius of those who could conceive the possibility of such results and who possess the ability to produce them.

CELLULAR STRUCTURE OF CAST STEEL.—MM. Osmond and Werth have been experimenting for several years in the laboratory at the workshops of Creusot upon the structure of melted steel. Preparing plates as thin as possible and fixing them to glass by the aid of Canada balsam, they were exposed to cold, weak nitric acid until the iron was dissolved, leaving a nitrate derivative of a hydrate of carbon, so as to reveal the distribution of the carbon in the steel. A microscopic examination shows that this distribution is by no means uniform and that melted steel is composed of small granulations of soft iron, which are generally separated from one another by cells of a carburet of iron. In other words, there is a kind of cellular tissue, the iron constituting the nucleus, and the carburet the walls of the cellules. These elementary or simple cellules are collected into compound cellules, which are separated by void lines. The lines form closed polygons, which are of large dimensions in the cast ingots, but which become smaller and smaller, broken and confused, in proportion as the metal is more perfectly worked. The contact faces of the compound cellules are composed of soft iron without the interposition of carburet. The compound cells may be readily identified with the grain of the steel and their faces are also regions of minimum cohesion.—*Comptes Rendus*, February 16, 1885.

FRICTION OF LEATHER BELTS ON IRON PULLEYS.

By Silas W. Holman.

The present investigation (completed in 1882) was undertaken with a double object: First, to make a somewhat more detailed study of the variation of friction with changes of velocity of slip in a few substances, and to make a further study of the friction of belts of leather and other materials over the surfaces of pulleys. It was also desired to ascertain how far the necessary arrangements would be suitable for an instructive laboratory experiment for students; a problem which has since been brought to a very satisfactory solution by others in the Mechanical Engineering Laboratory of the Massachusetts Institute of Technology.

The laws of friction between rubbing metallic surfaces, both lubricated and without lubricant, are yet open to careful research. Although the conditions of this case are comparatively simple, they are yet somewhat difficult of exact reproduction. The presence of dirt or traces of any material, which may act as a lubricant, must produce serious errors in the result. The complete removal of oil, used in the preparation of the surfaces, has been found a matter of difficulty, and this shows that all such use of oil should be avoided. The measurements of Coulomb, Morin, and Jenkin go far to show that with speeds from 0·1 inch per minute up to perhaps 5,000 inches per minute, the coefficient of friction of motion (kinetic friction) of many unlubricated metallic surfaces undergoes but little change; also, that the coefficient of friction of repose (static friction) is nearly, if not quite, the same as of motion.

It is to be noted, however, that the magnitudes of the errors in the experiments of the first two observers are so great, that it is impossible to claim that there is no change whatever, even within much narrower limits. Jenkin's measurements extend only from velocities of 0·1 inch per minute to 8 inches per minute, about, and although quite delicate, cannot be regarded as sufficiently numerous or positive to be of conclusive weight. The experiments of Bochet, upon the friction of iron at higher speeds, from four to twenty-two metres per second = 10,000 inches to 50,000 inches per minute, were made upon the action of brakes upon rail-

way trains, and show a decided diminution in the coefficient as the speed increases.

These are all the published experiments upon this point, with which I have met, but I have not entered into a careful study of the literature of the subject. The case of friction of metals upon wood without lubricant has been studied by Coulomb, Morin, and Jenkin, with the same general result. Kimball has shown, however, a diminution in coefficient with increase of speed in this case also, but finds further that the coefficient of friction in general "at very low velocities (under a few inches a minute) is very small; it increases rapidly at first, then more gradually as the velocity increases, until at a certain rate, which depends upon the nature of the surfaces in contact and the intensity of the pressure, a maximum coefficient is reached. As the velocity continues to increase beyond this point, the coefficient decreases. An increase in the intensity of the pressure changes the position of the maximum coefficient, and makes it correspond to a smaller velocity," etc.

When the experiments on lubricated surfaces of whatever description are considered, it will be seen that the discrepancies are far greater than with unlubricated. This is doubtless due chiefly to irregularity in the amount of the lubricant present, to a want of sufficient regard to the nature of the lubricant used, and to other similar experimental conditions. It seems unlikely that experiments upon plates sliding upon a horizontal plane with uniform motion, would give conditions of lubrication identical with similar plates moving with accelerated motion, with shafts revolving in journals, and with disks revolving one against the other.

Morin has found constant coefficients for lubricated metals, and Jenkin has arrived at sensibly the same result for very low velocities, with the exception of steel on steel with oil. For this he finds an increase of the coefficient as the speed increases. Kimball finds under conditions similar to those used by Jenkin, a similar rise in coefficient, attaining a maximum at a low speed (of about one inch per minute, or less in case cited) and then falling away towards a minimum of much smaller value (as low as one-third the maximum in one case) at high speed. The experiments of Jenkin and Kimball are on shafts upon their bearings.

In the case of metals upon wood with lubricant, the general result of Jenkin's experiments point to a rapid diminution of

coefficient as speed increases up to about eight inches per minute, and even higher. Observations of Morin give to these substances a static coefficient higher than the kinetic, and the remark made by Jenkin connecting these phenomena is a suggestive one.

The results of Coulomb, Rennie, Morin, Jenkin and Kimball are not, I think, to be regarded as contradictory. It must be considered that the measurements by Jenkin were at velocities in inches per minute from 0·1 to 8; by Kimball, from 0·007 to 3,000; by Morin, 70 to 9,000 (certainly not reliable below 70); by Bochet 10,000 to 50,000. Thus the experiments of Jenkin and Morin scarcely overlap, those of Morin and Bochet do perhaps slightly overlap, and those of Kimball cover a range corresponding to those of Jenkin and most of those of Morin, and extend considerably below those of the former. The results by Kimball and Jenkin are not contradictory and the data by Bochet seem to be a continuation of Kimball's results about such as might be anticipated. The field, as it is now opened, would seem, therefore, to invite a careful detailed study with the whole range of materials and velocities, under conditions of accuracy corresponding to the possibilities of modern mechanical construction, so that a *connected* series of reliable data should be reached.

Although my own work progressed but a little in the direction of the friction of solids, and none of the results are here given, I leave the above statement to present for comparison the results upon the friction of metals and those now to be described upon the friction of leather and iron.

Before I had become acquainted with the methods and results of Professor Kimball,* I had been led by some preliminary experiments both on the friction of blocks of wood upon inclined and upon horizontal planes, and on the friction of belts upon pulleys, to the conclusion that, at low speeds, the coefficient of friction did increase rapidly with the speed. Seeing the important bearing of this fact upon the question of the friction of belts upon pulleys, I have been led to an extension of these preliminary experiments to a more detailed study, in the hope of being able to demonstrate clearly for some special cases the law of the change of coefficient, and to thereby contribute somewhat to an interesting theoretical

* A. S. Kimball. *American Journal of Science*, cxiii. (1877).

question and to the data used in engineering practice in regard to belting.

In the case of a belt sliding over the surface of a pulley, there appears to be no objection to the use of the general formula of Morin,* giving as the coefficient of sliding friction:

$$f = \frac{log_{10} \frac{T}{t}}{0{\cdot}00758\ a}$$

where T = tension in tight side of belt,
t = tension in slack side of belt,
a = arc of contact between belt and pulley.

When $a = 180°$, this becomes

$$f = \frac{log_{10} \frac{T}{t}}{1{\cdot}364}.$$

This expression must not be applied to rapidly running pulleys without allowance for "centrifugal force" of the belt, but in the present study no such condition enters.

A complete description of the apparatus used in my experiments is unnecessary. In principle, it was as follows: A pulley was fixed upon a horizontal shaft, which could be kept in continuous and quite uniform rotation at any desired speed from zero to about thirty turns per minute. Over this pulley was hung the belt, whose coefficient of friction was to be measured, and to this was attached at one end (usually corresponding to the slack side of the belt) a spring balance reading up to 120 pounds, which was secured at its other end to a ring in the floor. Both ends of the belt were also provided with hooks, upon which weights could be hung.

To determine the rate of slip of the belt over the surface of the pulley, an electrical chronograph was improvised from a Morse sounder. By this were recorded seconds by means of a circuit closed by a seconds pendulum, and upon the same strip the times at which four electrical contacts were closed by a pointer attached to and revolving with the

* "Morin's Mechanics." "Rankine's App. Mechanics," p. 618.

shaft carrying the pulley. A careful measurement was made once for all of the distance through which the highest point on the crowned surface of the pulley moved, when the pointer passed from each of these contacts to the next. Thus by the chronographic record, the time during which the pulley surface turned through, a known distance under the belt was given, and from this the rate of slip was deduced by a direct proportion. All rates of slip were used from the highest attainable, which were far beyond the limits of practice, down to the lowest, which were not interfered with by the friction of repose. The tables show the rates used. Care was taken in all measurements of any series with any given belt, to use as far as possible always the same portion of the belt surface. With this precaution it was found that the arrangement was very sensitive, and would give very accordant results so long as the condition of the belt surface remained the same. The following tables give some of the results obtained.

FIRST SERIES.

Belt used, three inch, single, old, leather belt, moderately clean.

Pulley used, 13 inch x 4 inch iron pulley, with very smooth, polished face.

Tension T, on tight side of belt = 20·3 pounds.

t Pounds.	f	*Slip.* in. per m.	t Pounds.	f	*Slip.* in per m.
14·03	0·118	0·72	11·59	0·171	13·20
13·69	·125	0·83	9·56	·240	18·00
12·25	·160	3·00	9·56	·240	18·00
13·75	·123	1·15	13·34	·135	1·44
13·56	·128	1·15	13·38	·132	1·65
13·44	·132	1·32	14·47	·107	0·288
11·69	·175	5·76	14·50	·107	0·144
11·44	·184	6·60	14·56	·105	0·096
14·19	·114	0·48	5·44	·493	140·
14·06	·116	0·48	4·19	·502	279·
14·00	·118	0·55	3·31	·578	558·
11·81	·173	11·52	3·19	·590	558·
11·56	·141	13·20	6·31	·372	69·7
11·81	·137	11·52	8·06	·294	27·9

This series was made with a preliminary apparatus before the chronographic speed recorder was arranged. If the results be plotted with speeds as abscisses and values of the coefficient of friction f as ordinates, it will be found that the results are quite

concordant, and that they show a great change in the coefficient with change of rate of slip. An inspection of the tables will show that with the slowest slip, 0·096 inches per minute, the smallest coefficient, 0·105, was obtained; with the most rapid slip used, 558 inches per minute, the largest coefficient, 0·590 (or mean 0·584) was found. The increase in coefficient is very rapid for slow rates of slip. The consideration of such a plot for the later series, as that just suggested, will contribute greatly to a clear conception of the results. In this series no friction of repose as distinguished from that of motion was observable. Prolonging the line obtained by the plot backward to a slip of zero gives the very low coefficient of friction $f=0{\cdot}100$, a result which is discoverable, I think, solely because of the fact that my observations give results at such low rates of slip.

SECOND SERIES.

Belt used same as in first series.

Pulley used same as in first series.

Tension T, on tight side of belt, 50·4 pounds.

t Pounds.	f	*Slip.* In. per m.	t Pounds.	f	*Slip.* In. per m.
34·0	0·125	0·720	25·6	0·216	13·20
36·2	·106	0·240	35·7	·110	0·288
34·4	·122	0·825	36·1	·106	0·170
33·0	·135	1·44	36·5	·103	0·096
31·2	·153	2·88	35·6	·111	0·360
28·9	·177	5·76	37·1	·098	0·720
26·1	·210	11·52	34·5	·121	0·720

This series is in substantial agreement with the first series, showing that within these limits of pressure the coefficient does not vary with the pressure. The strain in the second series is about that of ordinary running belts.

FOURTH SERIES.

Belt used, two inch wide leather belt with surface rather dry and polished by use. Hair side of belt to pulley.

Pulley used, ten inch iron; face, dry and well polished.

The chronographic speed record was taken in this and all subsequent series, and groups of observations were taken on various days. Temperatures and humidities were also observed, and although the groups on different days showed slight, constant differences from each other, yet no connection between these

differences and the humidity could be traced. There were in all about 180 experiments made.

The following table gives mean values taken from a curve drawn through a plot of those which were made with 100·8 pounds on the tight side of the belt. The maximum coefficient of friction of repose found in this series was 0·242.

Slip. in. per m.	*f*	*Slip.* in. per m.	*f*	*Slip.* in. per m.	*f*
1·5	0·192	40·	0·291	500·	0·572
2·	·196	50·	·301	550·	·592
3·	·203	75·	·325	600·	·611
4·	·210	100·	·347	650·	·629
5·	·217	150·	·386	700·	·646
6·	·223	200·	·420	750·	·663
8·	·233	250·	·450	800·	·679
10·	·241	300·	·478	850·	·695
12·	·247	350·	·504	900·	·711
15·	·254	400·	·528	950·	·726
20·	·264	450·	·551	1,000·	·741
30·	·280				

FIFTH AND SIXTH SERIES.

A subsequent series (fifth), of about fifty measurements in all, showed the same general variation of f with the rate of slip with loads of 50·8 pounds on the tight side of the belt, and all of the results showed a gradual diminution of coefficient for any given rate or slip as the belt became progressively more dry and polished from friction on the smooth pulley. This lessening amounted to nearly fifteen per cent. between the first group of experiments and the last one made, indicating thus the large change to which a belt may be subjected from wear in continual usage.

A series (sixth), with the same pulley and belt, but with the flesh side of the leather to the pulley, gave coefficients, substantially the same as the two series just referred to, but about fifteen per cent. lower than the average values obtained with the other surface of the belt.

SEVENTH SERIES.

Belt used, a four inch, soft, thick, clean leather belt, which had been used but was in good condition. Hair side to pulley.

Pulley, the same as in fourth series.

The group m' was the first one made with this belt, and will be seen to show a striking increase of f as the slip increases. The

group m'' immediately succeeded m' and shows coefficients much larger than does m' indicating an increasing coefficient of friction as the surface of the belt was more used. The measurements of a succeeding group agreed substantially with those of m''. Group o was made under precisely the same conditions, except that the load on the tight side of the belt was $T = 101{\cdot}3$ pounds instead of $51{\cdot}3$ pounds as in m' and m''.

If these results be plotted, it will be seen that the resulting lines are much more convex upward than those for the fourth series, showing a much more rapid increase of f at small rates of slip, and a less rapid one at high rates. This appears to result purely from the nature of the belt. Other kinds of belting would doubtless show materially different changes of f with changing speed.

SEVENTH SERIES.

Group m'.		Group m''.		Group o.		EIGHTH SERIES. Group q.	
Slip. in. per m.	f	*Slip.* in. per m.	f	*Slip.* in. per m.	f	*Slip.* in. per m.	f
1·39	0·124	2·80	0·158	0·68	0·132	1·36	0·301
2·81	·130	2·80	·152	2·79	·145	2·80	·308
5·16	·144	1·36	·140	5·14	·164	5·14	·315
9·17	·165	5·16	·169	9·11	·188	9·11	·336
17·0	·195	9·15	·192	17·0	·233	16·9	·356
50·0	·274	17·0	·235	16·7	·233	16·9	·356
120·	·387	48·6	·348	48·0	·263	31·3	·384
180·	·435	48·0	·346	31·1	·315	50·0	·417
240·	·508	120·	·508	45·6	·357	120·	·511
480·	·600	240·	·663	120·	·580	180·	·544
720·	·625	480·	·745	240·	·725	240·	·461
960·	·748	Repose	·146	480·	·793	480·	·726
$T = 51{\cdot}3$ lbs.		$T = 51{\cdot}3$ lbs.		5·17	·169	Repose	·315
				Repose	·163	$T = 50{\cdot}8$ lbs.	
				$T = 101{\cdot}3$ lbs.			

EIGHTH SERIES.

To test somewhat the effect of lubrication, or of the oily condition into which belts often get in running, the two-inch belt used in the first and second series was soaked with sperm oil, and the pulley face was also thoroughly oiled. Two groups of measurements showed substantially accordant results, and one of them is given in the group q in the table. A comparison of this group, or a plot from them, with the results of series first and second, will show that the coefficients f for the group q are much larger

than for these, and that the increase of f as the rate of slip is greater is less in group q.

COMPARISON WITH RESULTS OF EXPERIMENTS BY OTHERS.

From the data given by Professor A. S. Kimball,* I deduce the following table. A comparison of this with my results will show that the increase which he finds in f is even greater than any which I have found, but that the coefficients are on the whole much

Slip. in. per m.	Rel. Coeff. of friction.	f	*Slip.* in. per m.	Rel. Coeff. of friction.	f
0·37	0·42	0·264	15·4	0·78	0·491
·52	·44	·277	34·1	·86	·541
1·1	·48	·302	80·3	·96	·604
2·3	·53	·331	104·5	·99	·623
2·9	·55	·346	228·8	1·00	·629
4·4	·58	·365			

larger. He gives also the following table of relative coefficients (but without data sufficient for the computation of f) in which he finds a maximum of f at a speed of 660 inches per minute and a diminishing value of f at higher speeds. I find no such maximum

Slip. in. per m.	Rel. Value of f.	*Slip.* in. per m.	Rel. Value of f.
18·	0·82	1,190·	0·96
92·	·93	1,980·	·82
660·	1·00	2,969·	·69

at speeds of slip up to 1,000 inches per minute, nor from my results is any such maximum indicated. This fact, however, does not, of course, in any way demonstrate or even indicate that there is not a maximum at high speeds. If there is, however, it must be beyond the range of the ordinary practice of belting.

Morin's experiments on the friction of leather belts, or iron pulleys, gave $f=0{\cdot}28$ about. This result would correspond to a slow velocity of slip on the belts and pulleys used by me.

An examination of the statements, made by Mr. Towne† will show at once that his manner of obtaining uniform results, "By being careful that the final weight was such as to produce about the same velocity of the slipping belt in all experiments * * *" was a necessity solely from the reason that the coefficient of friction

* A. S. Kimball. *American Journal of Science*, cxiii., 353, (1877).

† Towne. JOUR. FRANKLIN INST. lv. 89, (1868).

can have a given value at one velocity of slip, and at no other. It will also be seen, that in neglecting to make measurements at other velocities than that used (viz., 200 feet per minute), he overlooked the chief source of discrepancy between the results of various workers upon the subject, and obtained a result containing a purely arbitrary condition, viz., that of the velocity of slip at which his coefficient of friction was measured. The reasons why this high velocity gave good results, and why "it was found impossible to obtain any uniformity in the results when the attempt was made to ascertain the minimum weight, which would cause the belt to slip," are evidently these: First, for small velocities of slip, the coefficient of friction varies very widely for small actual differences in velocity—differences too small to be readily detected. Second, at high velocities the coefficient varies very slowly with change of velocity of slip. It is, of course, impossible to compare the experimental value $f=0.5853$ found by Towne with any result obtained by me, because there is no probability that the belts and pulley surfaces used, were at all the same in the two cases, and my results were not made at velocities above 1,000 inches per minute (83 feet). An inspection of my tables will, however, serve to show that, with all belts used, I have obtained values of f, both greater and smaller than that of Towne. The experiments of Mr. Towne, as is well known, were made by causing the belt to slip over a fixed pulley at a definite rate, and noting the weights used on the ends of the belt.

Mr. Edward Sawyer * finds the weight on the slack side, which will just suffice to stop the slip of the belt loaded with a constant weight at the other end and hung over a fixed pulley. He consequently finds coefficients much smaller than those of other observers, because the velocity of slip when the weight is finally adjusted is very small. He finds that "on polished cast iron pulleys, hard new leather belts require fully 75 pounds to hold 100 pounds; but usually the ratio is between 60 and 70 (slack side) per 100, corresponding to coefficient of friction from 0.17 to 0.12. Pieces of old belting, and thoroughly oiled, averaged better; some trials went as low as 56 per 100 ($f = 0.19$). Rawhide belting appears to hold very well, giving an average a little

* Sawyer. "*Proc. Soc. Arts*" Mass. Inst. Technology, Boston, 1881–82, p. 25.

over 60 per 100. Rubber belting averaged a little under 60 per 100." The method is, of course, open to the same line of criticism as that of Mr. Towne; for the coefficient determined was that corresponding to the slowest possible rate of slip, and the assumption of this as a standard rate, or as a rate at which the coefficient should be determined, is purely arbitrary. That this is the minimum coefficient is true, but that the use of the minimum coefficient will give the best results in practice is not proven. In point of fact, the coefficient which is actually in action in the average running belt is probably much larger than this. My own experiments also show me that the smallest coefficient obtainable from various belts does not correspond to the same rate of slip. Some belts begin to "stick" at higher rates than do others; and as the change of coefficient at these slow rates is very rapid, the assumption of the minimum observable coefficient made by Mr. Sawyer is doubly arbitrary.

My own experiments show clearly enough wherein one principal point of divergence between the various carefully devised rules for calculating belting lies. Some of these are based upon coefficients of friction derived from experiments at low rates of slip, some at medium rates, some at high rates, others are based directly on "good practice." If the same belt and pulley had been used by all the observers above quoted, each following his own method, the results would have been nearly as discordant as they now are. The question still remains, which is the best rule to follow? This I am not prepared to answer directly, for there remains an element still to be experimentally determined, viz., the rate of slip which exists in properly running belts on main and counter-shafts. That some slip, apart from the known "creep," always exists, can hardly be doubted. It is from measurements of the rate of this slip, which might easily be made by those having large and small belts running under suitable conditions, that further advance in the application of friction experiments to practice must come. The results will probably show that the coefficient to be adopted, depending necessarily on the slip to be allowed, must vary with the kind of work which the belt has to do. Apart from considerations as to the strength of the belt, it will be seen that a loose belt required to transmit an amount of power proportionate to its size, would slip upon the pulley at a gradually increasing

rate, until such a rate was attained that the coefficient of friction was large enough to maintain the requisite tension difference between the sides of the belt. If the belt were tighten a less difference in tension between the two sides would suffice to transmit the required power; therefore, the rate of slip and coefficient of friction brought into action would be smaller than before. If the belt were too loose, the slip would become abnormally large, either injuring the belt by excessive wear, or throwing it off the pulley. With too tight a belt on the other hand, the friction and flexure of the shaft become excessive. The size of the proper belt to be used for given work will be determined by these two limitations and that of avoiding an undue width of belt.

Since there is for any given belt so wide a variation in coefficient, which may be called into action as the slip changes slightly, it seems that exact computations will never be desirable in estimating the size of belting, and that the study of the laws of the friction of belts, at least on iron pulleys, will serve rather to give to the intelligent engineer a scientific guide to the limits within which the work of a belt of given size must be restricted, than to give him a fixed factor with which to compute the exact dimensions of a desired belt. The extension of such studies as the incomplete one which I have detailed to covered pulleys and under various other conditions, would doubtless develop many points of interest and value.

Rogers Laboratory of Physics,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
BOSTON, April 22, 1885.

BITUMINIZED BRICKS.—Some of the streets of Berlin have been paved with bricks which were impregnated with bitumen. They are found capable of absorbing from fifteen to twenty per cent. of bitumen, and they then become remarkably elastic, tenacious and durable. It is hoped that the pavement will not only be found more durable than any other, but that the surface will also furnish a surer footing for horses.—*Les Mondes*, November 15, 1884.

OFFICE MUCILAGE.—Put 1,000 grains of potato starch into 12,000 grains of water, and add fifty grains of pure nitric acid; leave the whole in a warm place for forty-eight hours, stirring it frequently; then boil it until it becomes thick and translucid; dilute, if necessary, with water, and filter; also, dissolve 1,000 grains of gum arabic and 200 grains of sugar in 1,000 grains of water, add fifteen grains of nitric acid and boil. Mix the two products.—*Comptes Rendus*, November 15, 1884.

On the JACKETING of WORKING CYLINDERS of STEAM ENGINES.

By A. S. Greene, C. E.

Among the various methods for increasing the efficiency of steam engines, and one that has been almost universally adopted, particularly in engines using large measures of expansion and in marine compound engines, is the system of steam jacketing the working cylinders. There are various ways of effecting this, but the most usual is to cast a cylinder somewhat larger than would otherwise be done and then to fit steam-tight within it, the smaller working cylinder, thus forming an annular space surrounding and extending its entire length, and to which steam of the boiler pressure and temperature may be constantly supplied. The cylinder heads are also cast with double shells, live steam being admitted to the space thus formed, so that the working cylinder is completely surrounded in all parts, with a space that can be supplied with steam of the highest pressure and temperature employed in the engine. By this means a part, at least, of the heat that would otherwise have been lost by the steam within the cylinder during expansion, is retained, or, more properly speaking, the heat lost by the expanding steam while performing work is partly restored by the abstraction of heat from the steam within the jacket. That only a part of the heat is thus restored is due to the fact that the cylinder shell opposes a certain amount of resistance to, and that a certain amount of time is necessary for, the transmission of the heat.

Of course, all the heat that is supplied to the expanding steam from the jacket must first be obtained from the original source, namely, the boiler; and the jacket being also subject to a further loss of heat from radiation from the exterior surfaces, it follows necessarily that the amount of effective heat for transmission into work by the medium of the jacket is much less than that drawn from the boiler to supply it. It is, in fact, a sort of "robbing Peter to pay Paul" process, with this disadvantage, that the amount received by Paul is very considerably less than that of which Peter has been robbed.

If it be really advantageous to reheat the expanding steam in the working cylinder, it would seem that some more rational and effective process, in which the resistance of the cylinder shell to the transmission of heat, and the loss from radiation, from the excess of exterior surface of the jacket over that of the actual working cylinder, would be avoided. This could easily be accomplished by supplying a small jet of steam from the main steam chest or steam pipe directly to the interior of the working cylinder, during the time of expansion, by means of suitably arranged and automatically operated valves. The ports for this purpose would necessarily be small; they need not be as large as the section of the pipe ordinarily used for supplying steam to the jacket, for the same amount of the heat supplied in this direct way would certainly effect a much greater amount of reheating than could possibly be done through the medium of the jacket.* If, as is generally believed, the loss of heat within the cylinder produces a condensation of the steam, which, instead of being deposited as water on the inner surface, remains as a kind of mist distributed throughout the interior, then certainly a jet of hot steam mingled directly with this mist must be more effective in reheating, and converting it into dry steam than the surface heating from the jacket.

The writer is well aware of the tenacity with which engineers, and particularly the builders of steam engines, cling to pet theories, especially after they have been so generally adopted in practice, and can readily understand that where profits are reckoned as a percentage of the labor and material employed in building machinery, the excess of these necessitated where the steam jacket is adopted, would be a powerful argument in its favor; but from an experience in the use of steam, extending over a period of more than twenty-five years, he has reached the clear and decided conclusion that there is nothing to be gained by the use of the steam jacket, or any equivalent, that can not be better and more rationally secured by other and more direct means.

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*The reader of this paper will find interesting matter relating to the admission of superheated steam to the cylinder in a paper on "Cylinder Condensation, Steam Jackets, Compound Engines and Superheated Steam, by George Basil Dixwell, Esq.," read before the *Society of Arts* of the Massachusetts Institute of Technology, Boston, April 29, and May 13, 1875.—Coleman Sellers, Prof. Mechanics, FRANKLIN INSTITUTE.

The steam engine being a machine for the transformation of heat into power, steam acting simply as a vehicle for carrying that power, the entire question, outside of mechanical details, is reduced to a question of heat. As it is axiomatic that a part cannot be equal to, or greater than, the whole, it is hard to understand how a part of a given quantity of heat can be made to yield more work than the whole of it, or that a given quantity of heat indirectly applied can be more effective than when it is directly applied; and yet this is exactly what is expected of the steam jacket, the jacket being supplied with a certain amount of heat only a part of which, it is well known, is to be effective within the cylinder, or in performing work. It is plain, that, of the heat supplied to the jacket, the loss due to the resistance to transmission through the shell of the cylinder, is a loss which does not obtain when the heat is supplied directly to the interior of the cylinder, and that the loss due to radiation from the exterior surfaces, which, though small compared to the total heat supplied to the jacket, must be vastly greater than that from the unjacketed cylinder, from the fact of the great excess of those surfaces, and the higher temperature constantly maintained beneath them. Again, the heat from the jacket, which is effective within the cylinder, must act in reëvaporating previously condensed steam, or in superheating, thus increasing the tension, and the steam of increased tension thus produced, is subject to losses of the same character within the cylinder, as if supplied directly from the main steam pipe at first, though the limits between which the losses occur may be different with the jacket from what they would be without it. Although the heat is constantly maintained in the whole jacket at all times, it can only be efficient in a part of the cylinder which is on one side of the piston, for, on the opposite side, it is communicated to the vacuum space and must be a dead loss for as great a time as it is a gain. Hence, the supposed gain attributed to the use of the jacket, it is believed, must be imaginary or due to some other cause.

It has been observed on several occasions, when running engines with the starting valve slightly open to one end of the cylinder to prevent thumping, that, although, during half the revolution communication was open directly to the condenser, causing a clear loss, the gain during the other half of the revolution was sufficient to appa-

rently compensate the loss, so that the revolutions were not reduced, nor the coal consumption materially increased; and this in one case with the low pressure cylinder of a compound engine, the valve being but slightly open and passing steam from the main steam pipe. A case is also remembered where a steam engine builder contracted with a mill owner to remodel an old engine and fit it for running his mill, for which he was to receive in payment the price of the coal saved in a certain time by the use of the remodelled engine, compared with that used by the engine of a rival builder running the same length of time.

The remodelled engine was carefully supplied with steam jackets, and with all the necessary accompaniments, but after a few weeks use, and, when it came to determining, by careful and accurate measurement, the quantity of coal consumed on which to base the payment, steam was carefully excluded from the jacket and air admitted instead, simply as a non-conductor to prevent loss of heat by radiation. It is needless to add that steam was not afterwards used in the jacket, and, notwithstanding this exclusion the engine continued to work with remarkable economy of fuel.

Whether there is any advantage to be derived from the use of the steam jacket or not, there are several disadvantages with which it is inevitably attended. There is extra material and labor required in the construction, and liability to loss of castings from their extra complicated nature, which cause extra first cost, besides extra weight and space occupied, together with the liability to cracking from unequal heating in getting under way, which are of special importance in the case of marine engines.

It is the writer's opinion that the best place to utilize the heat of steam in producing work is within the working cylinder, and not outside of it, preventing, as much as possible, the losses of heat, not by the use of the jacket, but with light sheet iron to inclose a corresponding space to contain air, which inclosure should be sufficiently tight to prevent circulation of the air and loss of heat from convection, and then carefully and thickly felted, and cased with wood outside of that. With the cylinder properly clothed, it is believed, better results would be obtained than by the use of the jacket, and certainly many extra pipes, valves, traps, and much annoyance, would be avoided.

Philadelphia, May, 1885.

FLORIDA SUGAR.

By Otto Luthy.

[*Abstract of remarks made at the Stated Meeting of the* Franklin Institute, *June 17, 1885.*]

It will be of interest to many of the members of the Franklin Institute to hear of the progress made in reclaiming the swamps and overflowed lands of Florida, by the Okeechobee Land Company, generally known as the Disston Enterprise.

I am not in the position now to dwell on the engineering achievements of this great enterprise. Hoping that the chief engineer of that company, Mr. J. M. Kreamer, will favor us sometime with a detailed description of his successful operations, I shall restrict myself to mention, that by the removal of obstructions, by the enlargement of natural waterways, and by the construction of drainage canals, a reduction of several feet of the water level of the Okeechobee Lake has been effected, and so far about 1,125,000 of acres of heretofore submerged land have been reclaimed, which, by the improved waterways, may now be reached 250 miles inland, by steamboats from the Gulf of Mexico.

The soil of this bottom land is a homogeneous heavy rich loam, largely composed of humus in depths varying from three to ten feet, and well fit for immediate cultivation.

It is easily understood in these times of continuous agitation of the sugar question, and when the Department of Agriculture in Washington encourages the farmers of all latitudes to produce the sugar the country now imports, that, with the extraordinary favorable condition offered by the Florida climate, the experiments of raising sugar should at once be made upon these fertile bottom lands.

I have the pleasure to-night to exhibit samples of the first sugar and molasses manufactured from cane grown upon these recovered lands, which were sent to me a few days ago, and which indicate a highly encouraging prospect for the sugar industry of that peninsulas

I report the following statements regarding these samples:

The sugar farm, on which the cane was raised, is located near Southport at the foot of Lake Tohopekaliga, about fourteen mile.

from Kissimmee City. Previous to the operations of the Okeechobee Drainage Company, it had been permanently covered with from two to three feet of water. The canal draining these lands was completed in February, 1883. In January, 1884, active operations were begun in clearing the reclaimed lands. Plowing immediately followed, and between February 14 and 20, 1884, the cane was planted, *one year subsequent to completing the drainage canal.*

The season has been unfavorable—a very dry spring and a very wet fall. The yield is, however, enormous, the stand perfect and the average length of cane fully matured twelve feet, many stalks measuring fifteen feet; average diameter of cane, one-and-three-fourths inches.

The harvesting of the crop was delayed till April 23, 1885, at which time the cane was still in perfect condition and growing; *five months* after all cane in Louisiana had been killed by frost.

These samples of sugar and syrup were made from *growing cane* (planted February 20, 1884,) on May 12, 1885. The juice then having a density of 9° B.; the grinding season thus lasting from December to May.

The apparatus for extracting the sugar was of a very imperfect and primitive kind, involving a loss of at least fifteen per cent. of juice in the "bagasse." No defecation or clarifying was attempted, and no addition made of any kind. With proper apparatus, the yield could be made fully twenty per cent. greater.

Average number of cane stalks per acre,	16,000
Gallons of juice obtained per acre,	4,000
Gallons of syrup,	700
Which, being sold at 40 cents per gallon, brought	$280

The cost to clear the land, fence and ditch it, seed cane, planting and cultivation, including all expenses up to grinding, was less than $100 per acre.

The present crop "ratoons" are remarkably fine, being far superior to the "plant" cane at the same season last year (June, 1884,) while the number of stalks per acre is fully double last season's crop. The crop will be at least seventy-five per cent. heavier than last year.

With a view of ascertaining the value of these new Florida products in the northern markets, I have made an analysis of the samples, which turned out as follows:

SUGAR:

Crystallizable, or cane sugar proper,	96·4
Uncrystallizable, or invert sugar,	0·3
Ash,	0·5
Moisture,	1·7
Organic non-sugar by difference,	1·1
Total,	100·0

MOLASSES:

Density, 39° Beaumé = 1·362.
One United States gallon (231 cubic inches), weighs 11½ pounds.

Cane sugar,	53·5 per cent.
Invert sugar,	12·2 " "

The sugar at once manifests itself as a very high grade raw sugar, and with improved machinery and rational working could be made of such good appearance and fine aromatic flavor, that it would readily sell for direct consumption. As it is, it is worth here about five-and-one-half to six cents, wholesale. The syrup equals the best New Orleans molasses and would bring, perhaps, from fifty to fifty-three cents per gallon, wholesale, in this city.

These results certainly justify further experiments on the largest practical scale, and we may expect to hear soon of the erection of a large central factory to work up in a rational manner the cane produced by a cluster of sugar farms.

Philadelphia, 220 Church Street, June 17, 1885.

CHLOROPHYLL AND ITS COMBINATIONS.—Some investigations of M. Guignet seem to show that chlorophyll is contained in envelopes, which are insoluble in petroleum ether, but soluble in alcohol. In pouring a solution by concentrated alcohol upon water, the chlorophyll is gradually precipitated by diffusion, but it takes the form of brown flakes, which appear completely changed. On replacing the water by alcohol at 50° the chlorophyll is precipitated in deep green flakes without any evidence of crystallization; but the product thus obtained is very impure. Chlorophyll is very stable in the presence of bases, behaving like a true acid and giving compounds which appear to be very well defined. In order to obtain in the crystalline state the combination of chlorophyll and soda, alcohol may be added to the aqueous solution of that compound. On evaporating over lime under a bell glass, water vapor is absorbed and the alcohol more and more concentrated until it deposits needles of a very deep green, which appear almost black. These needles are very soluble in water and present all the characters of a perfectly definite compound.—*Comptes Rendus*, February 16, 1885.

THE METALLURGY OF STEEL.

By Pedro G. Salom.

[*A Lecture delivered before the* Franklin Institute, *February 25, 1885.*]

Ladies and Gentlemen:—The Metallurgy of Steel is such a comprehensive subject, that it is impossible in one brief hour to give you more than the most general outline. It shall be my endeavor, therefore, this evening, to give you, first, a short sketch of the history of steel; second, a description of the three general processes employed in its manufacture; third, a description of the physical qualities of the various steels; fourth, their chemical constitutions; and, finally, some information of a statistical character that will give you some idea of the gigantic magnitude and vast importance of the steel industry.

There is still a great diversity of opinion as to what should be the proper definition of steel, and our learned doctors disagree on this as on every other subject. But the meaning of words, like plants and animals, develops, becoming more comprehensive, heterogeneous—or obsolete—restricted, as the case may be. It is certain that the old idea of steel, viz., a metal that could be hardened or tempered, as it is called, so as to resist the action of a file, has been greatly modified, as only a small fraction of the metal that is manufactured and known in the arts as steel, possesses such qualities. We may say in general, therefore, that all iron that has been melted and then cast into a malleable bar or ingot is steel. This excludes on the one side pig iron, which, although cast from a molten condition, is not malleable, and on the other side wrought iron, which, although malleable, has not been *melted and cast.* It should be observed, however, that the line of demarcation cannot be sharply drawn, for low carbon steel is simply homogeneous iron, possessing about the same physical characteristics as wrought iron, and white pig iron, or chilled iron, is simply high carbon steel. Whatever difficulty the public may have in explaining these apparent inconsistencies, and distinguishing these fine distinctions, there is little trouble among manufacturers who are familiar with the characteristics of the various steels.

The early history of steel is involved in obscurity, but it is tolerably well established that iron in various forms was known from 1500 to 3000 years B. C. The first iron used was undoubtedly of meteoric origin, as both the Greek and Egyptian names of that metal indicate. Iron is said to have been discovered by the burning of the forests of Mt. Ida, an accident somewhat similar to the one by which the Phœnicians are said to have discovered glass.

All the ancient writers of note, Diodorus, Pliny, Herodotus and Aristotle, mention iron and steel in their writings. The Egyptians must have been familiar with steel, as the inscriptions on the obelisks could only have been made with hard steel. The Phœnicians introduced the art into Greece, and from thence it passed into the Western world through the Roman Empire.

The development of the steel industry in England up to 1855 was exceedingly slow and insignificant, the old and primitive methods were still in use, and the total production of the United Kingdom in 1854 was only 40,000 tons, an amount (of a different grade, however,) which several establishments in this country can now produce in from ten to twelve weeks. The steel made was used almost exclusively for cutting tools, and was made in various ways, by immersing bar iron into molten cast iron, by direct reduction from the ores, like the old Catalonian process and by the cementation process, melting iron in a closed crucible with finely pulverized charcoal. But there was no process that could be employed on a commercial scale until about 1740, when, after the most laborious investigations extending over long periods of time, during which he failed again and again to accomplish his object only to renew his researches with greater zeal, Benjamin Huntsman was finally rewarded by the discovery of the crucible process, which, with slight modifications, is still used to the present day. At this time consumers of steel were compelled to pay the almost fabulous price of five guineas, or $25 per pound, and when we pause for an instant to consider the fact that steel rails can now be made for about $25 per ton, it is evident what strides have been made in perfecting the processes of steel manufacture.

To give a detailed description of the various methods that have been tried to produce steel, would consume the balance of our time. Suffice it to say that the most absurd means have been used in chemical reagents without regard to their action, or what was

expected to be accomplished. Various oxides and alloys, sal-ammoniac, soda, potash, borax, alum, glass, salt, burnt horse-hoof, lime, magnesia, tar, and a hundred other nostrums have been patented, but those only of commercial importance are the oxides and carburets of manganese, about which we shall speak later in describing the crucible and Bessemer processes. Even electricity was called upon to exercise some of its marvels upon iron, and thereby produce a superior steel.

Crucible Process.—We come now to the consideration of the three general processes used in the manufacture of steel, and the first in point of time, is the crucible process, which, until the advent of the Bessemer, was by far the most important method of making steel. (*Plate I.*)

In the crucible process, as practised at the present time, the material to be melted is first packed in the pots. This is done by weighing out in pans the scrap and blister steel, or whatever other material is used, depending upon the nature of the steel desired. About eighty pounds of this material are carefully packed in crucibles usually made of black lead. (It was formerly the custom to place the pots on a preparatory annealing grate, where they could get red hot; then transfer them to the furnace, and heat them to a white heat before putting in the charge, which was done by means of a funnel; but to charge a pot in a white-hot furnace in this manner was exceedingly awkward, as can readily be imagined.) The heat having been brought up to the melting point, the lids are placed on the pots, the covers taken off the holes, and the pots placed on little stands in the shape of truncated cones, made of fire clay or old crucible bottoms. The melter has no trouble from this time except that of seeing that his furnace is kept sufficiently hot to melt the steel. When coal or coke is used as fuel, instead of the regenerative gas system, far more attention is required of the melter to keep his furnace in proper condition.

While the melting is going on, preparations for the next heat must be made, which consist of cleaning the old pots from a previous heat (sometimes these pots last six or seven heats) weighing out the steel scraps and packing them as before.

The moulds also have to be in readiness to take the "heat" already in the furnace. They are generally made in two long, flat, rectangular bars, which, when placed together, form a space

the size of the desired ingot. They are fastened with rings slipped over the top, and held in place by driving wedges between them and the sides of the moulds. The moulds are carefully wiped, and then smoked by burning tar or pitch under them, with their face downwards; this is done in order to prevent the steel from sticking to them.

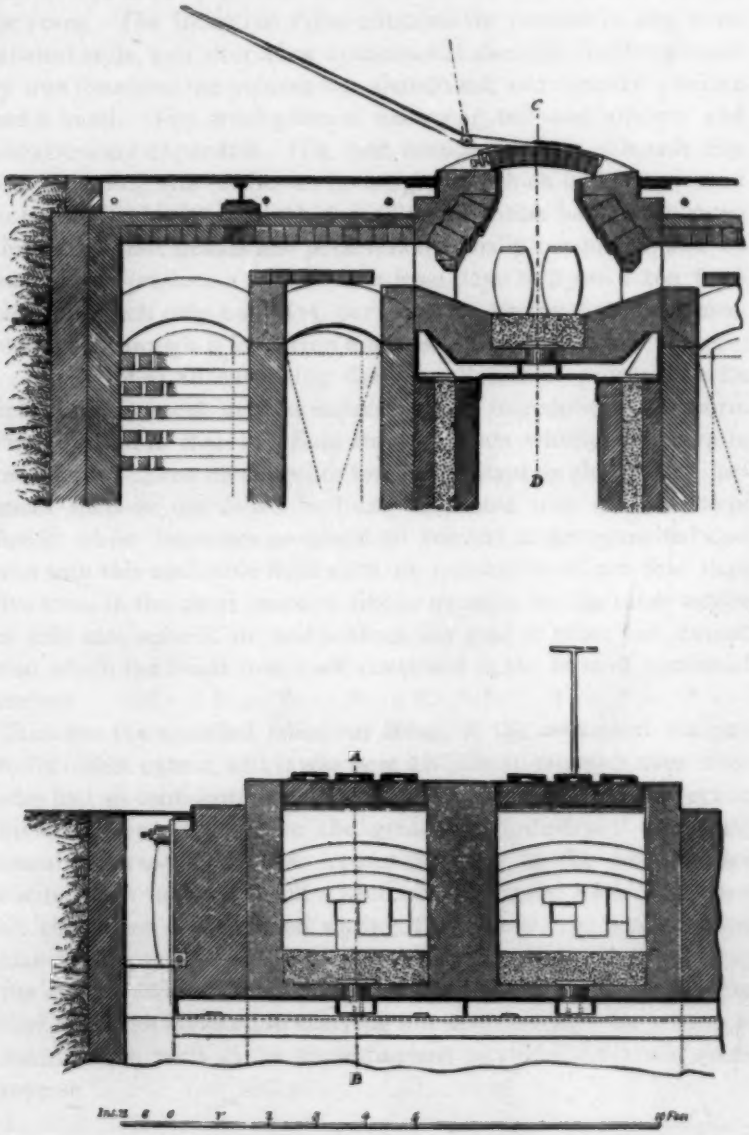
The melter now ascertains if everything is melted in the pots by moving the lid a little to one side, with a long iron bar or poker, and then stirring the contents of the pot with the same or a similar bar. This can also generally be ascertained by reason of the fact that, so long as the steel is not all melted, the contents of the pot appear to be in a state of ebullition, but when the steel is all melted, or "killed," the metal is as liquid as mercury, and "resembles, in its dazzling brilliancy, the sun." Everything being in readiness, the melter, or "puller out," having previously prepared himself by wrapping old pieces of carpet and sack-cloth around his waist and legs and over his feet, and placing a thick glove or mitt, extending almost to the shoulder, on his right hand, saturates his wraps with water, seizes a bell-shaped pair of tongs, and, the cover having been removed from the furnace, he places the tongs over and around the crucible, moves the pot slightly to loosen it from its fire-clay stand, and then, with a quick motion, stoops down, grasps the tongs lower down, near the pot, with his protected hand, and in rising brings the pot up with him, and with a swinging motion places it wherever desired. No more grotesque sight could be imagined than to see a number of those men, with their clumsy paraphernalia, moving around the furnace floor and taking the pots from the furnace.

The puller out removes the lid from the crucible, and the pouring or "teeming" takes place at once, for the metal is not like pig iron and cannot be handled for any length of time without chilling. The pot is seized by another man with a peculiar shaped pair of tongs, and poured carefully into the moulds, while a third man stands over him with a long skimmer or rod bent at one end, and prevents any slag from passing into the moulds. The red-hot ingots can be knocked out of the moulds in a few minutes and then taken away to be hammered or rolled, as the case may be. In either case they are found to be defective or piped about one-third of the way down, and this defect is not removed by subsequent

rolling. By this method of melting, one ton of coal will make one ton of crucible steel ingots, whereas in the old coke system it required about three tons of coke per ton of ingots. The holes are now made to hold four, six, and even eight pots. The operation requires about four hours, and therefore six heats a day can be made. The work is very severe (especially in summer time) on the melter or puller out, on account of the intense heat, and only the toughest and strongest kind of men can stand it for any length of time. It seems almost incredible that Krupp makes his large cannon by this primitive process, yet nevertheless this is the case, but it is done with such military precision as to be a matter of little or no difficulty. For manufacturing one of his largest guns, about 1,800 crucibles are required, each containing about sixty pounds of steel.

THE BESSEMER PROCESS.—Is the greatest metallurgical discovery that was ever made, and dwarfs into insignificance all other methods of manufacturing steel. It not only has revolutionized the iron industry, but also the sister industries in which iron plays the most important part, and is declared by M. Chevalier to be of more value than the discoveries of all the gold fields of California and Australia. Moreover, it is safe to predict that—by a closer study of the chemical nature of steel, that notwithstanding the marvels it has accomplished in the past—it will accomplish even more remarkable results in the future. It is probable that all grades of steel from the hardest tool steel to the softest and most ductile boiler plate can and will be made by the Bessemer or pneumatic process.

The history of the Bessemer process is replete with all the trials and tribulations that all great inventions have to pass through before reaching the commercial stage. Only a man of the most magnificent courage and indomitable perseverance could have carried it through to a successful issue. The difficulties to be overcome were gigantic, and would have appalled a man of less strength and faith in his convictions. He spent thousands of dollars, built furnaces, only to tear them down and rebuild them again, with, perhaps, a new idea suggested by a previous failure. When he read his paper before the British Association in 1856, after several years of laborious experiments, he was ridiculed by most of the metallurgical savants of England. They insisted: (1), that he could not accomplish what he claimed, (2), that even



MODERN CRUCIBLE FURNACE.

though he did accomplish his object the resulting product would be of no use, and (3), that, after all, it was no new discovery and that all the facts in the case were well-known and had been known for years. The Industrial Press criticised the process in the most satirical style, and after a few unsuccessful attempts had been made by iron founders, the process was abandoned, and declared a failure and a fraud. Two more years of unceasing toil and anxiety and $80,000 were expended. His best friends tried to dissuade him from pursuing any further an investigation which had commenced to tell on his health, and which leading engineers had pronounced chimerical. But genius and perseverance finally conquered, and he was able to produce a metal worth from $250 to $300 a ton from pig iron which only cost $35 per ton, by simply forcing atmospheric air through it for fifteen minutes. Jeans says:*

"It is not at all surprising that the Bessemer process, on its first announcement, evoked expressions of incredulity and scorn. Pure malleable iron in a fluid state was then wholly unknown in commerce. Even its exposure for several days in the hottest furnaces then in use failed to bring malleable iron into a state of fusion, while Bessemer proposed to convert ordinary melted cast iron into this malleable fluid state in quantities of not less than five tons, in the short space of fifteen minutes, by the mere action of cold atmospheric air, and without any coal or other fuel except that which the crude iron itself contained in the form of combined carbon. * * * * * * * * * *

Thus was the so-called fallacious dream of the enthusiast realized to its fullest extent, and it was now his turn to triumph over those who had so confidently predicted his failure. He could now see in his mind's eye at a glance, the great iron industry of the world crumbling away under the irresistible force of the facts he had elicited. In that one result a sentence had gone forth which not all the talent accumulated during the former 150 years, of the many thousands whose ingenuity and skill had helped to build up the mighty fabric of the British iron trade—no, nor the millions that had been invested in carrying out the then existing system of manufacture, with all its accompanying powerful resistance, could reverse."

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* "Steel: Its History, Manufacture and Uses;" p. 65. By J. S. Jeans.

The vessel in which the operation is conducted is called a converter, and consists of three parts, the dome or hood, the body or belly, and the bottom. These parts are usually made of wrought iron or steel plates, about one-half inch thick, and are bolted together by means of strong cast iron angle collars above and below. The body is also surrounded and firmly secured to a cast iron or steel belt or hoop, bearing the trunnions on which the converter revolves. One of the trunnions is solid and is connected with a spur wheel which is acted upon by a rack attached to the piston of an hydraulic cylinder. The other trunnion is hollow and is connected with the blast pipe by means of a stuffing box. The tuyere box (a flat cylinder made of iron or steel plate) and bottom are perforated with as many holes as there are tuyeres, and are bolted together, after the tuyeres, which are made of fire clay, have been securely luted in their places. The tuyeres are truncated cones and are pierced with from five to fifteen holes, varying from three-eighths to one-half inch in diameter, according to the size of the converter and the works. Their length is such that they are flush with the lining of the converter. The lining is made of gannister from six to twelve inches thick, tightly rammed between the shell of the converter and a wooden mould. The lining will stand as many as 1,200 blows, but the bottom and tuyeres wear out much quicker.

The pressure of blast varies from ten to twenty-five pounds per square inch, while the blast jets vary in number from 49 to 189. The ordinary converters of three or four tons receive the blast by forty-nine holes of one-half-inch diameter. In England and Belgium, the converters from five to seven tons have eleven tuyeres, with seven holes of five-twelfths-inch diameter. In the United States, eleven tuyeres are also employed, but generally with twelve holes.

One of the most important features of a converter is the facility with which the bottoms and tuyeres can be renewed when worn out, and their powers to resist such a high temperature as the converter is called upon to sustain, and it is probably due to the superior mechanical arrangements in American Bessemer works that enables them to make such a large output with a plant so comparatively small. Five hundred or 600 tons of steel are made regularly every day with only two converters.

Bessemer Bottoms.—The plan finally adopted, and now used almost without exception in America, and to some extent elsewhere, has a duplicate bottom, so constructed as to leave the annular space between it and the wall of the vessel open to the exterior of the vessel, so that a workman standing outside can ram the annular space, and thus make a sound joint without saturating it with water, and while the interior of the vessel is still red hot.

The worn bottom being removed by a hydraulic lift, or by any convenient means, the new one is inserted at once, and the annular space is quickly rammed with plastic cakes of gannister, thus making the lining continuous and solid. Sometimes a part of the wall of the vessel comes away with the bottom, and sometimes part of the bottom sticks to the wall of the vessel. The annular space is thus left so irregular that merely luting the new bottom and pressing it up could not make a good joint; but when all these irregular cavities are seen and filled from the outside, the joint is always sound.

Cupolas.—One of the important adjuncts of a Bessemer plant is the cupola for melting the pig iron. The cupola generally employed in American Bessemer works melts 100 tons in eighteen to twenty hours. The work required of it differs from a foundry cupola. It must deliver six tons an hour, at the highest attainable temperature, for a whole day and night. There must be a deep hearth or receptacle for slag under the tuyeres, and an upper tapping hole, by which the slag may be worked off, as in a blast furnace. The tuyere area must be excessively large, to insure ample air admission in case of partial chilling at any point, and the size, shape, and arrangement of the tuyeres must be such that they can be readily cleaned and changed without stopping the operation.

A cupola for a five-ton plant is of five feet internal diameter and fourteen feet high; it has six oval tuyeres of five and eight-inch diameter.

The blower used with the greatest success is the Sturtevant high speed fan blower.

Interposing ladles between the cupolas and converters are of service in many respects; the weighing of the charge is accomplished by this means.

In the best practice, 160 pounds of coke will melt one ton of iron.

The spiegeleisen is usually melted in a smaller cupola.

Cranes.—The cranes in a Bessemer plant are always hydraulic, constructed in a very simple manner, and do the required work with great ease and rapidity. The ladle crane is also an hydraulic crane and the ladle can be moved up or down and in or out without difficulty.

The hydraulic cranes used in Bessemer works consist of a vertically moving ram, to which a horizontal jib is attached. In ordinary cranes the jib does not move vertically, which is a serious comparative disadvantage, because all radial transference of the load must be done by racking the jib carriage, from which the load is suspended backwards and forwards by slow moving gearing or pulleys. When a jib rises and falls, its carriage may be moved radially by simply pushing the load. The carriage runs on the jib just like a car on a railway unhampered by sheaves and chains.

Ladles.—The ladles usually employed for casting Bessemer steel are constructed of boiler plate, lined with refractory sand, and furnished with a strong belt in cast or wrought iron, either made in a single piece and bearing two trunnions, which rest upon the arm or jib of the crane, or composed of two pieces bolted together. In the bottom of the ladle an opening is made both through the plate iron and the lining for the tapping hole.

The tapping hole is closed with an iron bar wrapped with clay and with a black lead stopper on the lower end, which is made to accurately fit the nozzle inserted in the bottom of the ladle. The other end is a goose neck, fastened to a casting attached to a sliding bar worked by a lever. By raising or lowering the lever the stopper is raised or lowered and the flow of the metal can be discontinued instantaneously, or regulated at will.

Ingot Moulds.—Ingot moulds are among the accessory appliances required for the Bessemer process. The best moulds are those where the thickness is so adjusted that the expansion is equal.

Hydraulic Regulators.—The hydraulic regulators are so arranged, that one or two boys by simply moving levers can keep all the cranes moving and regulate the motions of the converters.*

Tchernoff's description of the Bessemer process in the "Pro-

* Abridged from J. S. Jeans' "Steel: Its History," etc.

BESSEMER PLANT.

FIVE TONS OSCILLATING CONVERTER.

Fig. 2.

Section A.B.

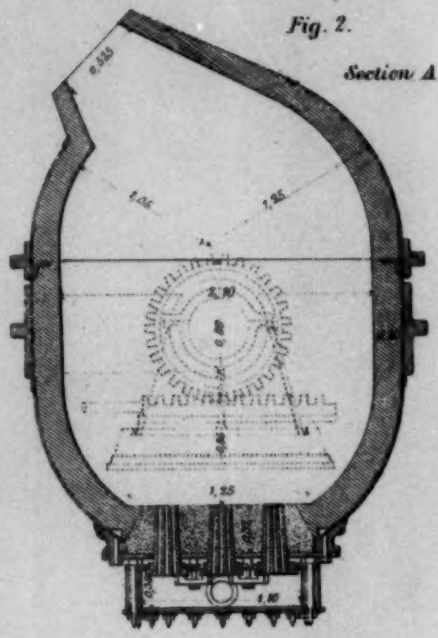


Fig. 1.

Elevation.

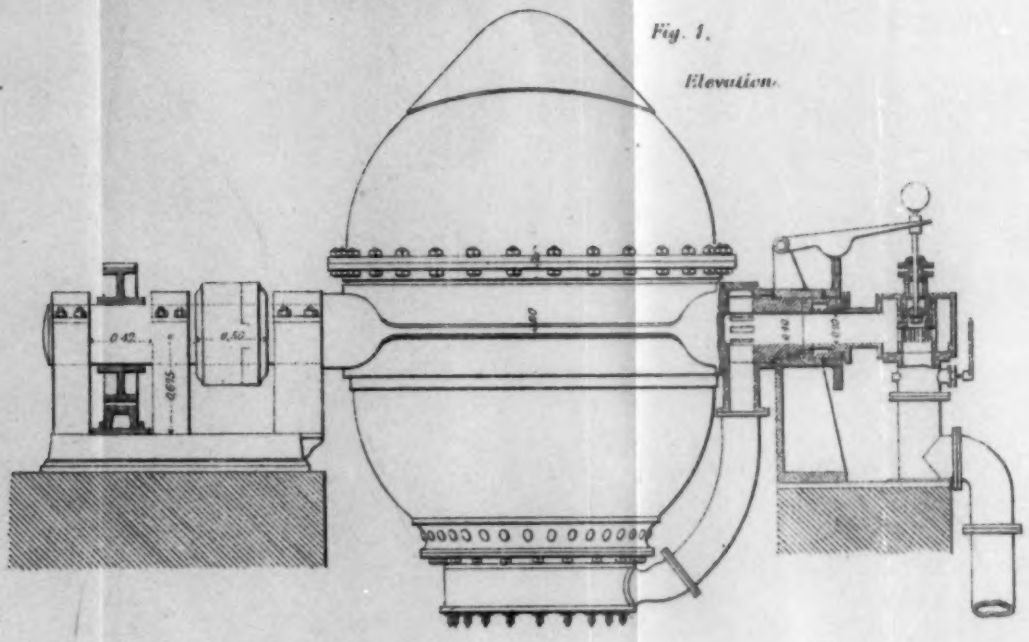


Fig 4.

Tuyere Box

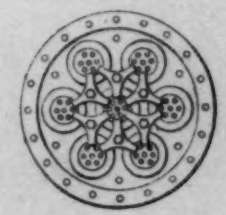
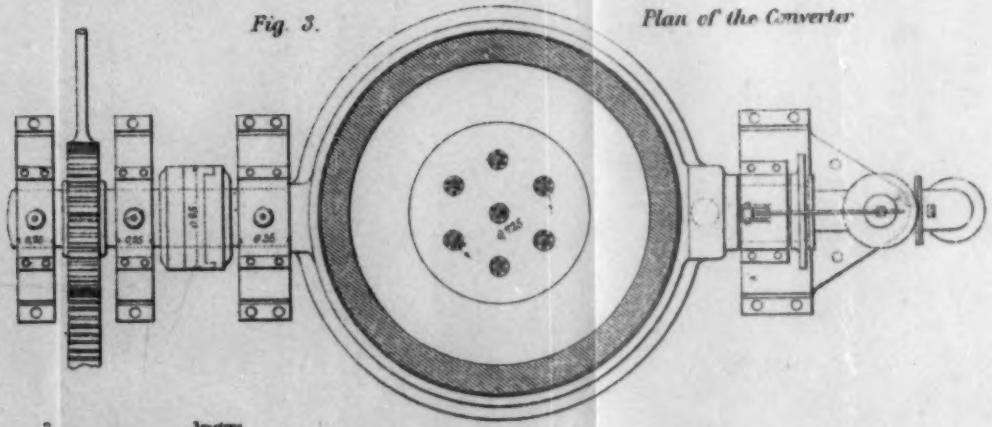
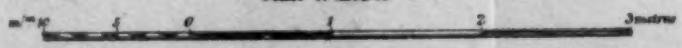


Fig. 3.

Plan of the Converter



Scale of Metres



ceedings of the Imperial Russian Technical Society," is so admirable, that I quote it almost in its entirety:

Description of Process.—In the Bessemer process, the retort previously heated is put into a horizontal position. Pig iron is then run in, coming by a channel from a cupola or reverberatory furnace, or in some places brought in ladles direct from the blast furnace. The apparatus being constructed for producing five tons of metal, the charge will occupy only a tenth part of the cubical contents of the converter. The pig iron being introduced, the blast is put on, and the converter brought back to the vertical position. As the pig iron reaches the tuyeres, it encounters the blast, which not only prevents it from entering the openings, but also forces its way through the mass of liquid metal with great violence, the pressure of the blast being seven times greater than that of the column of metal. At this moment the combustion of certain constituent elements of the pig iron begins. The gaseous products of this combustion are vomited forth from the neck of the converter into a chimney, while the impurities are thrown off from the metal, which, at the end of the operation, is almost pure iron. The amount of heat developed by this combustion is so considerable that, in spite of the progressive diminution of the fusibility of the charge, it remains as liquid as mercury. In this reaction, which lasts about twenty minutes, we may distinguish four periods. (*Plate II.*)

First Period.—As soon as the blast is put on we see, coming out of the neck of the retort, a feeble flame, conical in shape, of a yellowish red tint, and accompanied by an abundant shower of sparks. At the same time there is produced in the interior of the converter a noise similar to that which would result from blowing air into an empty vessel. After a few minutes this noise seems to issue from the neck only, where it localizes itself towards the end; the flame begins to turn blue and elongates, assuming the form of a cone and becoming brilliant. The sparks are then finer and less abundant. The blast forces itself more easily through the charge on account of its increasing liquidity, which permits an increase in the speed of the blowing engine, giving a longer volume of blast.

Second Period.—These phenomena characterize the approach of the second period. The change occurs suddenly, and a person

who observes for the first time the progress of the operation can easily note a very apparent alteration in the flame and the sound. This period lasts from two to four minutes without apparent change.

Third Period.—The transition to the third period is not so marked as that from the first to the second. In the course of this phase of the operation the sound increases, the length of the flame diminishes to fifteen or twenty feet, and its brightness is so intense that it becomes dazzling to the eye. As these changes in the flame occur the charge boils over in splashes of fluid slag. These splashes are sometimes so abundant and are discharged with such violence, that the shower of sparks spreads over a radius of several yards. Two or three minutes afterwards the discharges cease and the reaction continues without any apparent change in the flame or the sound. The duration of this period is nearly the same as that of the first.

Fourth Period.—The fourth period marks the end of the operation. The flame contracts and the sound diminishes abruptly. This period lasts but a few seconds, and if the admission of the blast is continued the reaction seems to assume again the characteristics of the first period. The flame disappears almost completely, the sound is diminished, the luminous cone reappears—with this difference, however, that in place of the shower of sparks of the first period an enormous quantity of reddish smoke is produced. The fourth period lasts from five to ten seconds, and terminates the process. The converter is returned to the horizontal position the blast is shut off and a certain quantity of spiegel iron rich in carbon and manganese is added to the charge, which gives to the liquid iron the quantity of carbon necessary for its transformation into steel, and by the reaction of the manganese frees the charge of the oxide of iron which impregnates it."

Gaseous Products.—The composition of the gaseous products of a converter in the different periods of a blow have been determined with as much accuracy as the difficulties attending such determinations would permit. These analyses show that at the beginning of a blow the gases are composed of nitrogen carbonic acid and free oxygen; next toward the second period the gases take up carbonic oxide in rapidly increasing quantities and hydrogen appears and remains constant to the end of the operation. The

presence of hydrogen is explained by the humidity of the blast. If not in the gases at the first period, it is probable that at the commencement of the blow it is absorbed by the metal in fusion.

The composition of the gases disengaged during the different periods of the operation, explains to us perfectly the external phenomena visible in the flame. Thus in the first period, the gases containing no combustible element, there is no noise; nor can the flame be long as everything is already burned. We see only the incandescent products of combustion. In the second period, a large quantity of carbonous oxide is escaping and is consumed at the expense of the oxygen of the external air, which occasions the noise. The flame assumes the shape of a cone, similar to the luminous part of a candle flame. In the third period, the volume of the gases exceeds in quantity the air introduced through the tuyeres. Finally, in the fourth period, the impoverishment of the combustible gases, diminishes the noise and shortens the flame.

Conversion of the Pig Iron.—The study of the conversion of the pig iron in the Bessemer converter shows that it is simply a refining process analogous to puddling. The following table will show this:

	Pig.	End Second Period.	End Third Period.	End Fourth Period	Steel.
Graphite, ...	3·180				
Carbon, ...	·750	2·645	0·949	0·087	0·234
Silicon, ...	1·960	·443	0·112	0·028	0·033
Phosphorus, ...	0·040	·040	0·045	0·045	0·044
Sulphur, ...	0·018	traces.	traces.	traces.	traces.
Manganese, ...	3·460	1·645	0·429	0·113	0·139
Copper, ...	0·085	0·091	0·095	0·120	0·105

The spectroscope was used to great advantage in the early days of the Bessemer process, but the process has been brought down to such an exact science that it is no longer necessary. What I particularly desire to emphasize to-night, is, the great possibilities that still lie dormant in the Bessemer process.

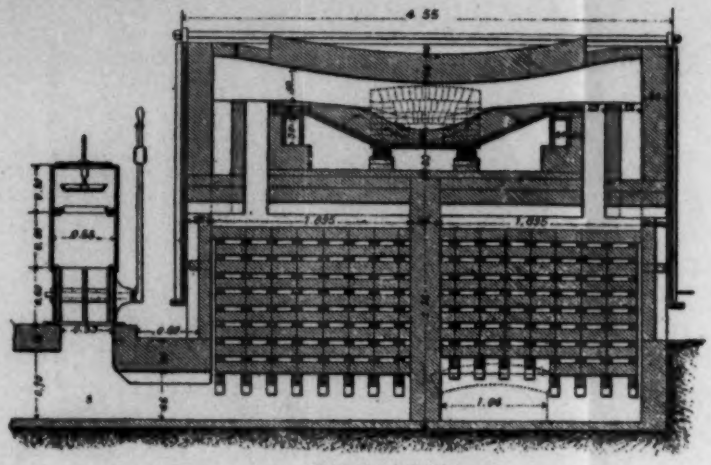
Springing as it did, like the telegraph, full-fledged into existence with all its startling effects, it has, with the exception of some minor

mechanical details, remained just as it came from the inventor's hands. It was years before any great improvements were made in telegraphy, but the time came when all sorts of ingenious contrivances from the "stock ticker" to the "telephone" were offsprings of the great parent invention, and so it is with the Bessemer process, the side issues of this invention are just beginning to be realized, and the basic or Thomas-Gilchrist process and the Clapp-Griffiths process, are simply indications of the various valuable modifications of which this process is capable.

OpenHearth, or Siemens-Martin, Process.—We come now to the third and last general process for manufacturing steel, viz., the Open Hearth, or Siemens-Martin, process. (*Plate III.*)

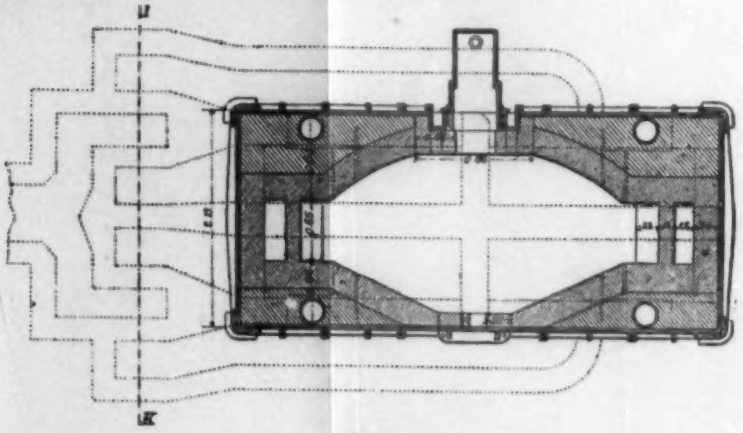
The furnace usually employed in this process is a large, cumbersome mass of masonry and brick-work, bound above and below with old rails or bridge girders. The furnace proper is encased in heavy cast or wrought iron plates which are lined with fire-brick a foot or more in thickness, and in addition to this, a thick bed of sand is spread over the bottom, which is fused into one solid mass when the furnace gets its heat. The roof was formerly made to dip towards the centre from both ends but now in some of the best and largest furnaces it is simply a plain flat arch. It should be built of the most refractory brick that can be obtained; pure silica brick being usually employed for this purpose. The inside of the furnace and the air and gas ports are also lined with silica brick.

Below the furnace proper are the four regenerative chambers which are loosely filled with fire bricks (called the checquer work), in such a manner as not to impede the free circulation of air and gas through them. These chambers connect with the furnace through small passages, called the "ports," and with the gas producers and chimney through underground flues. The underground flues are so arranged in connection with valves, that the air and gas are admitted separately to the two chambers on one side of the furnace, pass through the chambers and into the furnace through the ports, where they are united on the hearth of the melting chamber, the waste products of combustion pass through the ports on the other side down through the chambers, giving up their heat to the checquer work and finally pass through the flues, out the chimney, comparatively cool. The current is reversed by means of the valves about every twenty minutes, and the incoming



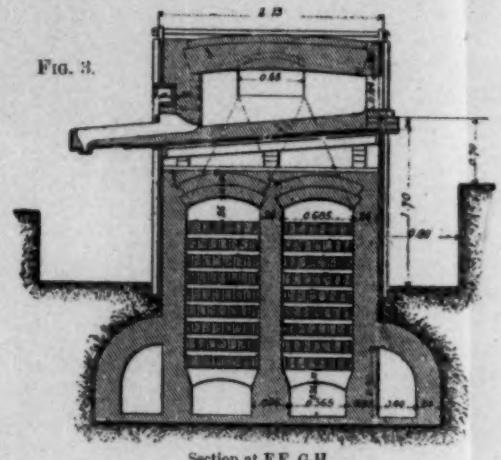
Section at A B, C D.

Fig. 2.



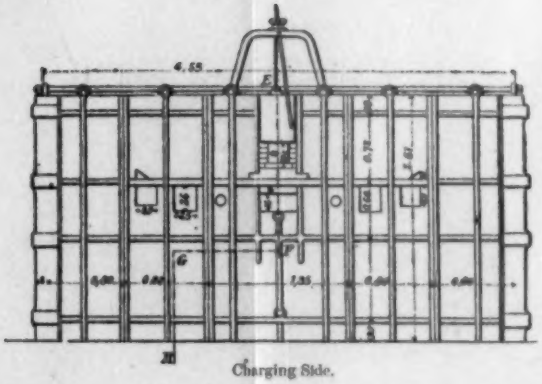
Plan.

Fig. 3.



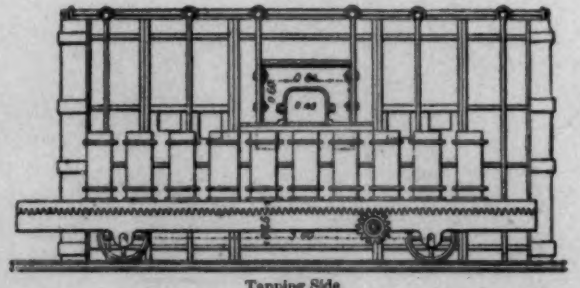
Section at E F, G H.

Fig. 4.



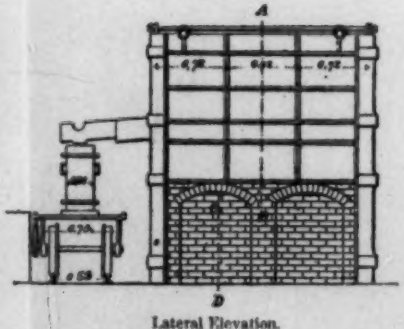
Charging Side.

Fig. 5.



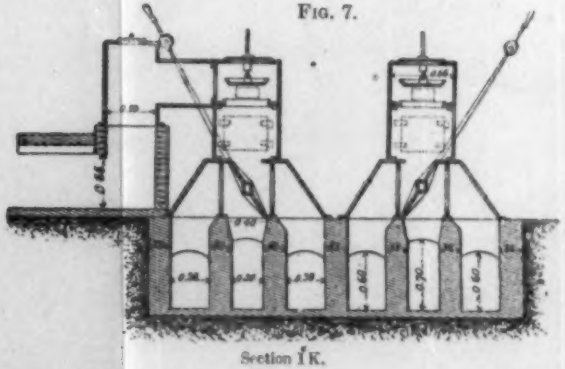
Tapping Side.

Fig. 6.



Lateral Elevation.

Fig. 7.



Section I K.

THREE-TON SIEMENS-MARTIN FURNACE AT SIREUIL STEEL WORKS.

gas and air are thus heated to a very high temperature before uniting, thereby increasing the intensity of combustion.

Methods: Pig and Ore, and Scrap.—There are two methods employed in making steel in the Open Hearth furnace. In the first method pig iron alone is melted and decarbonized with ore; in the second, besides the pig iron charged, wrought iron either in blooms or muck bar, and scrap, are used to reduce the carbon of the pig. In the pig and ore process, to the pig iron, after having been charged and melted (which requires four or five hours), pure iron ore is charged cold into the bath in quantities of 400 or 500 pounds, a violent ebullition takes place, and when this has abated, a new supply of ore is thrown in, the object being to keep up uniform ebullition as nearly as may be. Of course care is taken that the temperature of the furnace is maintained sufficient to keep the bath of metal and slag sufficiently fluid, but after the lapse of some time, when the ore is thoroughly heated and reduction is taking place rapidly, the gas may be in part shut off from the furnace, the combustion of the carbon in the bath itself keeping up the temperature. In the course of the operation the quantity of ore charged is gradually reduced and samples taken from time to time of both slag and metal, and when these are satisfactory, spiegeleisen or ferro-manganese, is added and the charge cast. This mode of working takes a little more time than the scrap process, and the consumption of fuel is rather larger. Starting an Open Hearth furnace requires much more time and labor than starting a converter.

The operation is commenced by building a fire in the producers, and when they have a sufficient body of red-hot coal, say from five to ten tons, the gas may be cautiously introduced into the furnace, which has been previously heated by burning wood and coal on the hearth. The introduction of the gas into the furnace is often attended with considerable difficulty and danger, for if the pressure is relaxed for an instant, or there is a back draught, there is sure to be an explosion or "kick," as it is generally termed. This is caused by the air not being all expelled from the gas chamber, an explosive mixture of gas and air resulting. Sometimes these explosions destroy the flues and break the arches of the regenerators, necessitating a stoppage of several hours or even days. Soon after the admission of the gas, the furnace begins to heat up very rapidly, and after reversing a few times, begins to get

red hot. In a large (fifteen ton) furnace, it takes about twenty-four hours, before the melter can begin to make bottom. This is done by shovelling in sand, which soon sets at a white heat and closes up all the cracks made by the expansion at the beginning of the operation.

As soon as the bottom sets, the melter is ready to make the charge, which is generally conveyed to the furnace floor some ten or twelve feet above the ground by means of an hydraulic elevator.

The charge consists (supposing we are making a boiler-plate heat of fifteen tons) of about 5,000 pounds pig iron which forms the initial bath. To this, after being melted, is added about 10,000 pounds of scrap, in the shape of furnace scrap from the previous heat and the shearings from rolled plates. When this has partially melted, 15,000 pounds of the best Bessemer muck bar or charcoal blooms are charged in several thousand pound lots, so as not to chill off the furnace too much. It was formerly the custom (and is still in some places) to preheat all this material before it was charged into the furnace, but now it can all be charged cold without any inconvenience. The melting requires between five and six hours, and sometimes even longer. When the heat is completely melted, which is ascertained by the melter putting a long iron hook into the bath and moving it around, the bath is well stirred and a sample taken out for inspection or analysis. The melter can tell from this sample whether it is necessary or not to decarbonize by the further addition of blooms or muck bar and, when ready, the amount of the final additions to be added, which consists of about 150 pounds of a very high manganese pig iron (containing about eighty per cent. manganese) known in the arts as ferro-manganese. As soon as the ferro-manganese is added and the bath is stirred or rabbled vigorously, the heat should be taken out immediately, for if it is allowed to remain in the furnace the oxidation continues and the metal is injured. While the charging has been going on, preparations have been made in the pit and floor for receiving the metal. A large number of ingot moulds are placed on the "group plates" with a central runner, on top of which is a fountain all lined with fire-brick or clay. When everything is in readiness, the ladle, which is made of heavy iron plate riveted and lined with fire-brick, and which has been heated red

hot, is brought under the spout and a heavy iron tapping bar is driven into the furnace by means of a ram. The metal comes out with a rush and with a dazzling brillancy, scattering thousands of sparks over everything. The sight at night is a very beautiful one, although not equalling the Bessemer. When the charge has all run out of the furnace, the ladle is brought over the fountain on top of the runner, the stopper raised, and the metal, passing down the central runner, radiates in several directions, and runs into the ingot moulds from below, gradually filling them to any desired height. This is called bottom pouring and insures a much better ingot than by merely pouring the metal in the top of each mould. The tapping-hole is closed again and, the bottom having been repaired, is ready for another charge. The whole operation can be completed in seven or eight hours, thus enabling the production of three heats a day, the operation being continuous.

Pernot.—Some of the Open Hearth furnaces are constructed with a movable or revolving hearth, and they are then known as the Pernot furnace. They diminish the time required for melting, but they are much more costly and are exceedingly difficult to keep in good working order.

An Open Hearth plant, while not so expensive to construct as a Bessemer, is far more costly to operate, owing to the relatively small production and the difficulty and time consumed in repairs, and the necessity of using iron in some refined shape, either as muck bar or charcoal blooms, which are very expensive. The quality of the steel, however, can as yet be made far superior to that of the Bessemer.

THE PHYSICAL QUALITIES OF STEEL.—There are few subjects that have been so carefully studied as that of the physical nature of steel. The most elaborate investigations and costly experiments have been made, and although our knowledge has become considerably enhanced by the results obtained, still not nearly so much has been accomplished as these elaborate experiments would seem to indicate, and we are still in lamentable ignorance.

When a bar of steel is placed in a testing machine, constructed for the purpose and actually pulled apart, there are four physical qualities which may be observed.

(1.) Tensile strength or the weight per square inch, required to break the bar.

(2.) Elongation or ductility or the amount the bar has stretched between two given points.

(3.) Elastic limit, or the weight per square inch that can be applied without giving the bar a permanent set.

(4.) Reduction of area, or the area at the point of fracture compared with the original area.

The tensile strength and elongation are the important elements, while the elastic limit and reduction of area are a complement or corollary of the first two.

The tensile strength of steel varies from 50,000 to 200,000 pounds per square inch, and with it, of course, the other properties vary. No quality of steel is more readily affected by its composition and treatment than its tensile strength. For every employment for which steel is used, steels of various tensile strengths have been tried; yet, notwithstanding the fulness of the information on this subject, engineers and manufacturers are still unable to agree in some cases as to the proper tensile strength to use.

The elongation or ductility of steel varies from nothing to thirty-three per cent. in an eight-inch section. It is the greater ductility of steel that renders it superior to the best iron in the construction of boilers, ship plates, fire boxes, etc.

The ductility of steel is in most cases its most valuable quality. Strength without ductility is of little value to the constructing engineer. Tool steel is very strong, but no one would recommend it for boilers. Something that will bend before breaking is the great desideratum. Then it is an easy matter to so proportion the structure that no portion of it shall have an undue load or strain. Some years ago the engineers of the Pennsylvania Railroad were surprised to find that some steel bridge rods had broken in service. Samples of the steel were sent to Altoona, and physical and chemical tests made. The result of the investigation proved the anomalous fact that the rods broke because they were too strong; that is to say, the steel having a very high tensile strength (about 100,000 pounds) would not yield to slight inequalities of mechanical construction, and therefore the strain coming on a single point, broke the rods.

Had the rods been made of steel with a tensile strength of 60,000 pounds and fifteen or twenty per cent. elongation, they would have bent and thus allowed the strain to come on the whole rod instead of on a single point.

The elastic limit varies from 15,000 to over 100,000 pounds per square inch, while the reduction of area varies from nothing to seventy per cent.

The following table will show the physical characteristics of steel made for various purposes by the three methods described above:

	Tensile S.	R. of Area.	Elongation in 2 inches.
American Tool Steel, ...	129,000	—	12 per cent.
Bessemer Steel (for rails), ...	81,000	—	17 "
Open Hearth Steel (for springs), . . .	143,000	—	6 "
Open Hearth Steel (for boilers), . . .	60,000	65 per cent.	30 " (in 8 in.)

The tensile strength of the best Sheffield tool steel is about 130,000 pounds.

Bessemer and Open Hearth steel can be made with tensile strengths, varying from 50,000 to 150,000 pounds.

The physical properties of a piece of steel are greatly influenced by the amount of "work" (rolling or forging) that has been expended upon it.

An interesting illustration of this fact was given by Mr. Hunt, in a paper read before the Engineers' Society of Western Pennsylvania. An ingot, twenty-four inches in diameter, was forged to sixteen inches and test pieces taken from disks, cut from the forging. A part of the forging was reduced to eight inches square and test pieces taken in like manner from it; another portion of the same material was rolled into a three eighths-inch plate, and test pieces taken from it. These test pieces were broken in the testing machine and all being of the same chemical constitution, viz: Carbon, 0·28; manganese, 0·60, the different results obtained are clearly due to the different amounts of work put on each piece. A piece from the original ingot was not tested, but would have had a tensile strength of about 45,000 or 50,000 pounds, and no elongation. The following are the results of the other tests:

	Tensile Strength.	Reduction.	Fracture.
16-inch forging, . . .	60,000 pounds	5 per cent.	granular and brittle.
8-inch forging, . . .	75,000 "	14 "	less granular.
⅛-inch plate, ...	85,000 "	18 "	fibrous and tough.

THE CHEMICAL CONSTITUTION OF STEEL.—The study of the chemistry of steel makes us have a wholesome respect for the value and importance of little things. When we come to consider the fact that three or four hundredths of one per cent. of carbon

affects the tensile strength of a piece of steel, we begin to understand the value of any method by which we may obtain a rapid and accurate knowledge of the amount of this substance present. Moreover, we will understand why the results of the thousands of physical tests that have been made are still unsatisfactory. The incompleteness of these results seems to be more from the manner in which the tests have been made, rather than from any impossibility or inherent difficulty in obtaining the required information. That is, in a vast majority of cases they have been made without regard to the chemical contents of the steel. The physical test will tell us *what* qualities a certain piece of steel possesses, but it will not tell us *why* it possesses these qualities. This chemistry will do. What we require in order to have an accurate knowledge of steel is a series of alloys of iron with carbon, phosphorus, manganese, silicon, etc., alone and in combination with each other. We shall then be able to determine the influence of a unit of each of these substances on iron; our knowledge will be no longer merely empirical, and we will be able to foretell the physical properties of steel with as much accuracy as we do the properties of a substance obtained by a chemical reaction.

The influence of carbon on steel is better known than that of any other substance which enters into its composition. No one, however, so far as I am aware, has done anything more than formulate the general law that tensile strength increases with the carbon, other things being equal. I have made the interesting observation that this increase is almost exactly 1,000 pounds for every $\frac{1}{100}$th of one per cent. of carbon. That is to say, assuming $\frac{1}{100}$th of one per cent. of carbon to be a unit of carbon, then if to 45,000 pounds (the tensile strength of pure wrought iron) we add as many thousand pounds as there are units of carbon, we shall be able to make a very close approximation to the tensile strength. Boiler plate steel for example has about ·15 per cent. carbon and 15+45=60, or about the tensile strength of boiler plate steel. Rail steel has about ·30 per cent. carbon and 30+45=75, or about the tensile strength of rail steel. Again, crucible tool steel contains from ·50 to ·85 per cent. of carbon and these numbers added to 45, 95 and 130 respectively, include the tensile strengths of various kinds of tool steel. Still again, a sample of spring steel tested at

Altoona showed 1·00 per cent. of carbon; its tensile strength, therefore, should be 145,000 pounds. Its actual tensile strength proved to be 143,000 pounds. Of course, this law only holds good where other things are equal. An undue amount of one or all of the other foreign substances that enter into the composition of steel, or unusual physical conditions, would change the results entirely. It may be of value, however, in pointing out the fact that, when steel with a known amount of carbon does not possess a certain tensile strength, then the other substances entering into its composition are present in undue proportion or it must have been made under unusual physical conditions. The influence of manganese on steel is much more of a disputed question than that of carbon. Some metallurgists believe it to be extremely injurious, while others hold it to be very beneficial. There is no question, however, about its effect on steel so far as tensile strength is concerned, which increases as the percentage of manganese increases, although not so rapidly as with carbon. I believe, however, that when alloys of pure iron and manganese are made, it will be found that the increase of tensile strength is not due to manganese *per se*, but to its power of causing carbon to combine with the iron. In other words, it has not yet been shown; so far as I am aware, that an alloy of iron and manganese without carbon possesses unusual tensile strength. But manganese plays a dual part, it not only increases tensile strength, but, in the process of manufacture, it reacts powerfully on the oxide of iron which the steel contains and forms a fusible slag, which, being specifically lighter, rises to the top when the steel is in a molten condition, and thus renders it more homogeneous and consequently stronger and more ductile. This, however, is only true up to a certain point, beyond that point the steel gets more and more brittle until two per cent. is reached, when the steel is so brittle that a bar or rail can readily be broken by throwing it on the ground. It has recently been discovered, however, that if the percentage is increased to seven per cent., that this brittleness commences to disappear and the metal, although exceedingly hard, begins to get tough again, and when it is increased from twelve to fifteen per cent., the metal is harder than the best tool steel and almost as tough as boiler plate. I have recently seen a piece of this remarkable steel, which had a tensile strength of over 100,000 pounds to the square inch and an elonga-

tion of twenty per cent. in two inches. The alloy is the invention of Mr. Hadfield, of Sheffield, England, a well known crucible steel manufacturer. I have been unable, as yet, to formulate any definite law regarding the influence of a unit of manganese. In order to do this, a knowledge of the physical qualities of pure manganese should first be obtained, as no reliable experiments have ever been made to demonstrate these qualities. That it is a matter of the first importance, and of exceedingly great scientific interest, all must admit.

It does not seem probable that pure manganese would possess a tensile strength greater than pure iron; if it does not, must not the increased tensile strength of manganese steels be due to the combined carbon?

There is a greater difference of opinion regarding the influence of phosphorus than perhaps any other element that enters into the composition of steel. It has been considered by a majority of the best authorities that phosphorus is a hardener. The result of an immense number of tests that I have made, point in exactly the opposite direction. I have found that phosphorus in steel acts in the same manner physically as it does in pig iron, and, if I may be allowed the expression, is a "rotter," not a "hardener." But even this generalization has to be somewhat modified, for as far back as 1874, 'M. Euverte, of Terre-Noire, discovered that phosphorus might be introduced into steel on condition that the proportion of carbon was correspondingly diminished, and that the less carbon the steel contained, the more phosphorus might be admitted into it without depriving it of its valuable properties.

I believe, however, that this is only relatively true, and that the same metal, without any phosphorus, is possessed of superior qualities.

I have recently seen some steel test pieces made by the Clapp-Griffiths process that contained as much as 0·50 per cent. of phosphorus, an amount which only a few months ago (and even now by a large number of steel makers) would have been considered as rendering steel utterly useless, and yet this same steel possesses more valuable qualities than wrought iron and can not only be flanged and welded, but will stand being bent double cold without cracking.

The influence of silicon on steel has been but little studied, but in my opinion it has a more injurious effect than phosphorus. We

know in a general way that silicon acts in an opposite manner from manganese and prevents the carbon from combining with the iron. Phosphorus acts in a similar manner, I believe, for it is a well known fact that high phosphorus pig irons will not "chill;" that is, the carbon will not combine with the iron.

Again, we do not know whether silicon is present as silicide or as silicate of iron. Phosphorus, in the same way, might be present as phosphide or phosphate of iron, thus making important physical changes.

But silicon possesses the remarkable property of making steel solid. When ordinary low carbon steel is cast into an ingot, it is honeycombed, or full of "blow holes." Now, if we introduce into the steel 0·2 or 0·3 of one per cent. of silicon, these holes disappear, and it is possible, therefore, to make steel castings as solid as those made of iron, and with a strength from three to four times as great. At the same time, these castings are almost as ductile as wrought iron.

Sulphur and copper make steel red short, but they are usually present in such small quantities as not to give the manufacturer any serious trouble, and therefore their precise influence has not been so carefully studied as that of other impurities. Thus we see that our knowledge only being partial, we cannot as yet predict with any certainty what influence various proportions of an impurity has.

There seem to be some characteristics about steel, however, that neither chemical nor physical tests will explain—characteristics in connection with its molecular condition; and it is possible, in this connection, that the microscope will prove an important aid. At all events it is an almost virgin field, and a conscientious microscopic analysis of steel would undoubtedly yield the most interesting results.

The future of the iron and steel industry is difficult to foretell, and, although it is far from probable that it will develop in the next fifty years with such rapidity as it has in the last three decades, yet it has not by any means reached that zenith point whence future progress is impossible, and from which point the decline in its importance begins. What I desire to-night to particularly emphasize and impress upon you, is the magnificent possibilities the Bessemer process still possesses. The puddler and the

crucible process "must go." No thoughtful man can witness the operation of puddling, or the crucible process, without being impressed with the primitive nature of our methods. They must be improved, or new ones invented. Here is a splendid field for scientific and mechanical ingenuity. In conclusion, let me say that any industry in which so many millions of dollars are invested, and which gives employment to so many thousands of men, is worthy of your profoundest consideration.*

Table of Statistics of the Iron and Steel Trade, from the Annual Report of the Secretary of the American Iron and Steel Association. Production of the world in 1883.

	Pig Iron. Gross Tons.	Steel. Gross Tons.	Coal.
Great Britain,	8,490,224	2,158,880	163,737,327
United States,	4,595,510	1,673,534	96,159,719
All other countries,	7,990,837	2,445,227	138,114,795
Total,	21,076,571	6,277,691	398,011,841
	$20	$50	$3
	420,000,000	310,000,000	1,200,000,000

It will be seen from the above that the United States produced twenty-two per cent. of all the pig iron, twenty-seven per cent. of all the steel, and twenty-four per cent. of all the coal produced in the world in 1883. If we value the pig iron at $20, the steel at $50, and the coal at $3 per ton, we find this output to represent the enormous sum of nearly $2,000,000,000.

Production of Iron and Steel in the United States and Pennsylvania in 1883.

	United States.	Pennsylvania.
Pig Iron, (net tons 2,000 pounds),	5,146,972	2,638,891
Rolled Iron,	2,348,874	1,081,163
Bessemer Rails,	1,286,554	819,544
Open Hearth Rails,	9,186	
All Rails,	1,360,694	857,818·63 per cent.
Crucible Steel Ingots,	80,455	63,687
Open Hearth Steel Ingots,	133,679	72,333
Bessemer Steel Ingots,	1,654,627	1,044,396
All Steel,	1,874,359	

From the above figures we are justified in feeling a reasonable pride in the preëminent position that Pennsylvania occupies in the iron and steel industry of the United States.

* The lecturer illustrated the subject by the exhibition of numerous test specimens.

BOOK NOTICES.

THE NATURE OF GRAVITY. By Wm. Coutie.

Mr. Coutie is a manufacturer of steam engines and machine tools, in Troy, N. Y. He has devoted much of his leisure thought to the study of natural forces, embodying the results in a brief essay, in which he endeavors "to show that the force which unites an atom of Oxygen to an atom of Hydrogen to form an atom of water, is the same force which unites the sun and planets in their orbits, and that the ultimate atoms of all matter constantly give out those actions known as light, heat, force and gravity; that these are but different manifestations of the self-same thing, and that their combined action produce all the phenomena of Nature."

The conviction of an ultimate unity of force is as old as the days of Greek philosophy. The evidences which have been furnished by the thermo-dynamic, electric, and photo-dynamic investigations, in confirmation of such unity, have led to the system of absolute measurement, and to the introduction of a series of units based upon mass, length and time, which may be used in all kinetic measurements. Mr. Coutie appears to have gone over much of the ground which is covered by such measurements, without being aware of the extent to which his views had been anticipated.

He has displayed so much acumen in his investigations that he may well be encouraged to continue them. There is great need of many additional numerical determinations in the line of his studies, and there is some probability that if he will make such determinations, he may be led to new and important discoveries; but there will be little gained by attempting to attract public attention to the mere probabilities of a correlation of forces, which is already generally believed, although it can hardly be regarded as demonstrated.

P. E. C.

THE SOARING BIRDS. A Mechanical Problem. By I. Lancaster, Chicago, Illinois.

Mr. Lancaster has published a small pamphlet under the above title, and he also published an article in the London *Engineer*, in 1883, upon the same subject. His object in writing his paper is "to point out the direction in which effort will most likely lead to practical results; as an aid to those interested in working out the problem of artificial flight." He has a confident belief "in man's ability to navigate the atmospheric spaces at will, the only thing still remaining undone being a matter of mechanical construction, requiring neither great expenditure of money, time nor skill."

The author's views are not presented in such a form as to be satisfactory, either to mathematical or non-mathematical readers. The properties of parachutes and the direct action of atmospheric currents upon broad surfaces are correctly stated; but there are some views, in regard to the reaction of the air and a consequent propulsion against the wind, which are at variance with commonly accepted notions. It is claimed, however, that the correct-

ness of those views has already been partially confirmed by experiments, and we would cordially encourage the author to continue such experiments, until he can either find in what respects he has been mistaken, or can secure such degree of success as will satisfy those who are skeptical. P. E. C.

A Correlation Theory of Color Perception. By Charles A. Oliver, A. M., M. D. Reprinted from the *American Journal of the Medical Sciences*, January, 1885.

Dr. Oliver starts from the undulatory hypothesis of light and the adaptation of each sensory organ to receive its own variety of impression. He supposes visual sensation to begin in the retina, by the primary change of an external, natural force into an equivalent nerve energy. This primary form of sensation is conducted inwardly and spread upon the intra-cranial retina, in such a form as to be readily converted into an equivalent perception, by the aid of some unknown process of mentality.

The line of investigation is a novel one; the experiments are ingenious; the results are interesting. We cordially commend the paper to the notice of our readers, and we look hopefully for important confirmation of the results which it indicates, by the pathological data which the author promises to present in support of his views. P. E. C.

The Architect's and Builder's Pocket-Book. By Frank Eugene Kidder, C. E. John Wiley & Sons, New York.

Nothing is easier at the present day than to make a pocket-book on engineering or architectural subjects: yet nothing is more difficult in this line than to form a *good* one, for considerable knowledge of the contents is necessary, and a scientific conscience also in selecting, explaining and condensing. The writer had a friend, whose method of making a pocket-book was unique. This individual had a number of them relating to railway curves, and of nearly equal size; so he tore out of each what he wanted, sent the selection to a bookbinder, and the latter issued the edition.

Every practitioner has several pocket-books, if not many, since nearly each one contains something which suits his bent of mind. Indeed, some engineers regulate their practice by them (not a good policy, yet explaining the great number in the market). The one under consideration is well written, with clear engravings, and contains much information. Quite a set of designs for roofs is given, taken from actual buildings; and if some are not exempt from criticism, they are all interesting and instructive. Those of Gothic style are for the most part selected with taste. A complete set of tables, clearly arranged, is also given for the calculation of strains in rolled iron beams.

C. A. E.

Distribution of Red Stars.—M. Pechüle, of the Copenhagen Observatory, has made a spectroscopic study of the stars in the Southern hemisphere. He found a large number of red stars, increasing in frequency in proportion to the proximity of the milky way.—*Les Mondes*, October 9, 1884.